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ADVANCED LIFE ANALYSIS METHODS - User's Manual for "LUGRO" Computer Program to Predict Crack Growth in Attachment Lugs

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NOTICE

This technical report has been reviewed and is approved for publication.

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This report is Vol. VI of a 6-part final report on the work conducted under AFWAL contract ~~No. F33615-80-C-3211~~. The objective of this research program is to develop the design criteria and analytical methods necessary to ensure the damage tolerance of aircraft attachment lugs. This volume describes the computer program LUGRO developed under this contract and provides user input instructions and input and output data for some sample problems. LUGRO is an automated computer program which has been developed using the state-of-the-art methodologies to predict the residual strength and fatigue crack growth behaviors of single through-the-thickness cracks and single corner cracks at attachment lugs. → to p. 1

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ADVANCED LIFE ANALYSIS METHODS - User's Manual for "LUGRO" Computer Program to Predict Crack Growth in Attachment Lugs (Unclassified)

FOREWORD

This is Volume VI of six final report volumes on Contract F33615-80-C-3211, "Advanced Life Analysis Methods." The work reported herein was conducted jointly by Lockheed-Georgia Company and Lockheed-California Company under contract with Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB. J. L. Rudd is the Air Force project leader.

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SECTION I

INTRODUCTION AND COMPUTER PROGRAM DESCRIPTION

This report is the sixth and last volume of the final report generated under Air Force contract F33615-80-C-3211 entitled "Advanced Life Analysis Methods". The objective of this contract is to develop the design criteria and analytical methods necessary to ensure the damage tolerance of aircraft attachment lugs. In this contract, an extensive analytical and experimental investigation was conducted to characterize and predict fracture and growth behavior of cracks in attachment lugs. The titles of the six volume final report generated under this contract are listed below.

Volume I	Cracking Data Survey and NDI Assessment for Attachment Lugs.
Volume II	Crack Growth Analysis Methods for Attachment Lugs.
Volume III	Experimental Evaluation of Crack Growth Analysis Methods for Attachment Lugs.
Volume IV	Tabulated Test Data for Attachment Lugs.
Volume V	Executive Summary and Damage Tolerance Criteria Recommendations for Attachment Lugs.
Volume VI	User's Manual for "LUGRO" Computer Program to Predict Crack Growth in Attachment Lugs.

This volume (Volume VI) describes the crack growth analysis computer program LUGRO developed under this contract and provides user input instructions and some sample input and output data.

LUGRO is an automated computer program which has been developed using the state-of-the-art methodologies to predict the residual strength and fatigue crack growth behaviors of single through-the-thickness cracks and single corner cracks at attachment lugs. This section further describes the operation of the program, functions of the main program and the subroutines, and a flow-chart of the computer program.

Originator-supplied key words included: → p. 1473

The program includes the following four basic elements:

- o Stress intensity factor solution
- o Baseline crack growth rate relationship
- o Applied load sequence
- o Spectrum load-interaction model

Stress intensity factor solutions for attachment lugs developed under this contract for a variety of structural and loading complexities can be found in Volume II of this final report. Some of these solutions have been embedded in this computer program, which can be used to interpolate the data to the desired lug geometry. The program also has the option to input the user-generated stress/stress intensity data.

The optional baseline crack growth rate relationships embedded in the program are those of Paris, Forman, and Walker. The optional spectrum load-interaction models incorporated in the program are: the Wheeler, Willenborg, Generalized Willenborg, and Hsu models, or assuming no load interaction. The crack growth rate equations and the spectrum load-interaction models are discussed in detail in Volume II of this final report. The stress levels which comprise each individual mission segment, and from which a mission mix spectrum can be generated, may be input in five optional ways: as maximum stress (σ_{max}) and stresss ratio (R); σ_{max} and minimum stress (σ_{min}); σ_{max} and mean stress (σ_{mean}); σ_{mean} and alternating stress (σ_{alt}); or R and stress range ($\Delta\sigma$). The program predicts the crack growth using a block-by-block integration technique.

For through-the-thickness cracks, either the compounding solution or the Green's function solution can be used in the prediction. In predicting the growth behavior of a single corner crack, the through-the-thickness crack solution may be modified by either the one-parameter (compounding method with constant a/c ratio) or two-parameter method (Green's function method). For one-parameter analysis, the prediction is straightforward and is similar to through-the-thickness crack prediction. For two-parameter analysis, it is assumed that for a given number of applied load cycles, the extension of the quarter elliptical crack border is controlled by the stress intensity factors at the intersection of the crack periphery at the

hole wall and the lug surface, i.e., K_A and K_C. In general, the stress intensity factors at these two locations are different, resulting in different crack growth rates. Therefore, the new flaw shape aspect ratio after each crack growth increment will be different from the preceding one. The new crack aspect ratio is computed using the new crack lengths on both the hole wall and lug surface. The process is repeated until the crack length along the hole wall is equal to the lug thickness. At that time the transitional crack growth criterion is used, until the crack has achieved a uniform through-the-thickness shape. After that, if the failure has not occurred, a one-dimensional through-the-thickness crack analysis is used to continuously predict the subsequent crack growth life. The analysis is considered to be complete when fracture occurs due to fracture toughness or net-section yield criterion or when the desired final crack length or the maximum usage time is reached.

The LUGRO program contains one main program and 14 subroutines. The functions of the main program and the subroutines are described below.

MAIN - The main program receives the input of basic data for the crack growth life prediction; interfaces with the subroutines; and outputs the predicted crack growth history.

DADNDK - This subroutine reads the baseline constant amplitude crack growth rate data in the form of da/dN vs ΔK or directly as material constants. In the former case, for each straight line segment of da/dN vs ΔK data (in log-log scale), the subroutine calculates the material crack growth rate constants using the crack growth rate equation specified by the user.

SPECTM - This subroutine reads and generates one complete block of stress spectrum to be used in the crack growth prediction. This block of stress spectrum will be repeated until the computed maximum stress intensity factor reaches the fracture toughness value or the net-section stress value reaches the yield strength of the material.

The prediction will also be terminated when the crack length or the accumulated flight time in terms of blocks reaches the specified maximum value in the input.

GROWA - This subroutine estimates the crack length as a function of accumulated flight time (or usage). The computations for through-the-thickness cracks are made in this subroutine. For corner cracks, the computations are made in subroutine CORNER, which is called by this subroutine. The predictions will be terminated if the computed K_{max} reaches K_c, or the net-section stress value reaches the yield strength of the material, or the current crack length or the accumulated flight time exceeds the maximum value specified in the input.

SIF - The stress intensity factors for a through-the-thickness crack are generated in this subroutine for crack lengths ranging from 0.0001 inch to the desired maximum crack length specified in the input. This subroutine calls the appropriate subroutines to calculate stress intensity factors using the compounding method or Green's function methods, or interpolating the tabulated data that have been input or are already available internally in the program.

SIF8 - This subroutine computes the stress intensity factors at the intersection points of a quarter-elliptical crack front at the hole wall and lug surface by modifying the through-the-thickness solution with various correction factors.

BACKS - This subroutine estimates a back surface correction factor for a part-through corner crack.

CORNER - This subroutine calculates the two-dimensional growth of a corner crack as a function of accumulated flight time

(or usage). This subroutine does the same functions as the subroutine GROWA, except that this is for a corner crack. Also calls the appropriate subroutines and computes the transition and subsequent through-the-thickness crack growths.

COMPND - This subroutine computes the stress intensity factors using the simple compounding method.

GREENF - This subroutine computes the stress intensity factors using the Green's function method.

TRANSG - This subroutine computes the transitional crack growth from when the corner crack breaks through the back surface to when the crack becomes a uniform through-the-thickness crack.

DADP - This subroutine calculates the average crack growth per block of stress spectrum as a function of any given crack length.

DADNJJ - This subroutine calculates the crack growth rate for each computed effective stress intensity factor range (ΔK_{eff}) and ratio (K_{mineff}/K_{maxeff}).

EFFKDA - This subroutine calculates effective stress intensity factor range (ΔK_{eff}) and ratio (K_{mineff}/K_{maxeff}), and estimates the corresponding crack growth increment using the specified crack growth retardation equation.

DIRCAL - This subroutine contains the stress intensity factors and the stress distributions as a function of outer-to-inner radius ratio of lug in a tabular form. The user has the option to use these tables and interpolate the data for the desired lug geometry.

Two more subroutines are referenced in the program. They are FUNCTION subroutines GIRC and DTAB2, which are UNIVAC library subroutines. GIRC is a single variable Aitkin interpolation subroutine and DTAB2 is a two variable interpolation subroutine.

A flow-chart showing the interactions between the main program and the subroutines is shown in Figure 1-1. The main program first processes the material crack growth data in DADNDK and develops the loading spectrum in SPECTM. Then it starts the crack growth analysis by calling the subroutine GROWA. The through-the-thickness stress intensity factor solutions are computed first by calling the subroutine SIF. Based on the input specified by the user, these stress intensity factors are obtained by using one of the various methods as shown in the flow-chart. Then depending on the crack shape (through-the-thickness or corner) the program branches to compute the crack growth behavior using subroutines DADP, EFFKDA and DADNJJ. In the case of corner cracks, the through-the-thickness crack solutions are modified with various correction factors for corner crack stress intensity factors in subroutine SIF8. Subroutine TRANSG computes the transitional crack growth behavior of corner cracks.

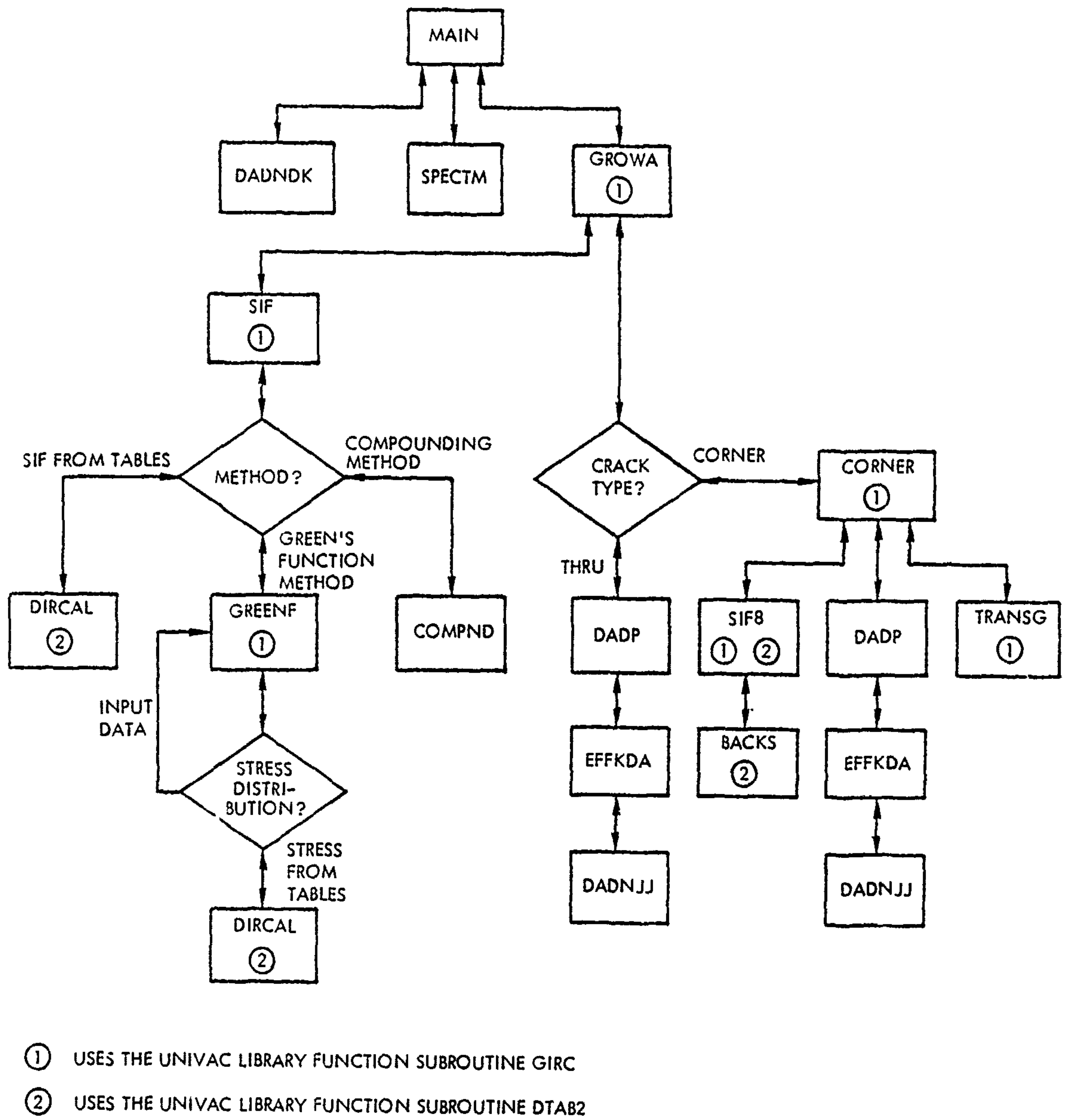


Figure 1-1. Flow-Chart of the Computer Program LUGRO

SECTION II

INPUT INSTRUCTIONS

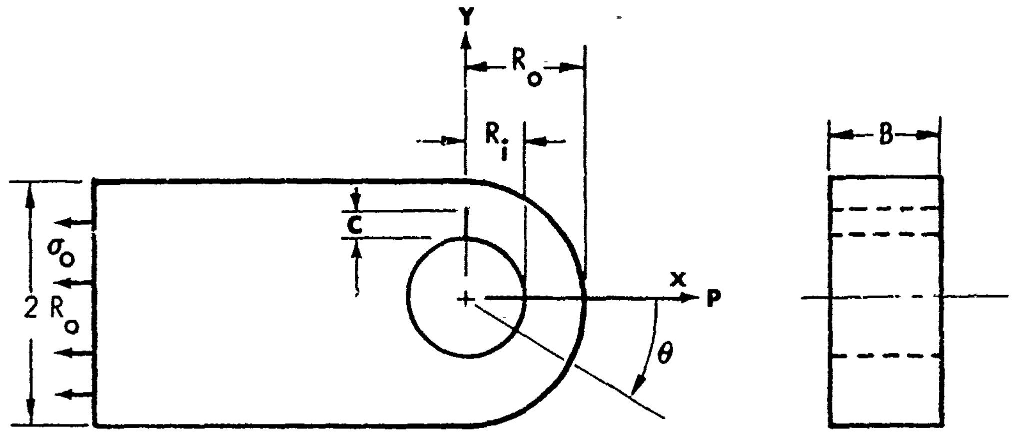
This section describes the input instructions for the computer program LUGRO. The program can be used to predict the residual strength and fatigue crack growth behaviors of single through-the-thickness cracks and single corner cracks at attachment lugs.

The program is capable of analyzing attachment lugs with and without interference-fit bushings. Figure 2-1 shows the geometries and nomenclatures of attachment lugs with and without bushings. In the case of corner cracks, there are three distinct regions of crack growth, namely corner crack growth until the crack breaks through the thickness, transitional growth until the crack reaches a uniform through-the-thickness shape and the subsequent through-the-thickness crack growth. These three regions of crack growth and corresponding definitions of crack length are illustrated in Figure 2-2.

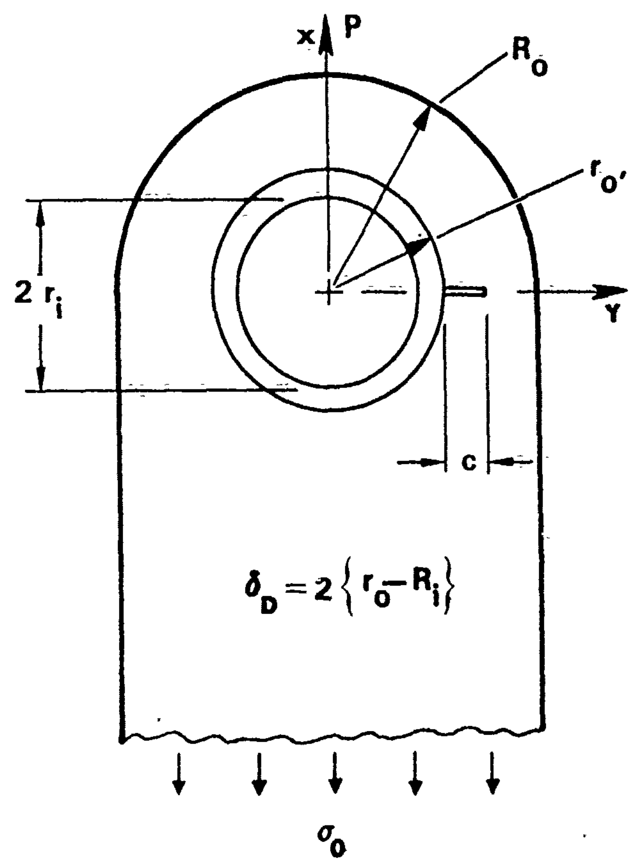
The input instructions for the computer program LUGRO to predict the residual strength and crack growth behaviors are provided in Table 2-1. There are 25 different lines of input as shown in the table. Some lines may have to be repeated several times depending on the nature of input. These are indicated under the column 'COMMENT'. For example, the da/dN vs ΔK data (Line 4) have to be repeated 'KPOINT' times, which is specified in Line 3. The table also describes the variables, type of variables and the columns in which the data are input for all the 25 lines of input. Sufficient instructions are provided in the table to choose the right set of input lines. For example, appropriate lines 3, 4 and 5 should be input based on the value of 'IEQU', which specifies the selected crack growth rate equation. The table also describes the cases when there will be no inputs for some specific lines. For example, when the value of 'IBETA' is equal to -1, there are no inputs for lines 20, 21 and 22.

The input variables specified in the 25 lines of Table 2-1 are described in detail in Table 2-2. The table also describes some of the terminologies used in the description and two important notes (Notes A and B) at the end of the table. The units with which the inputs need to be

specified are also given in the table. This section is followed by the sample problem section in which details of input and output are provided to aid the user.



(a) Simple Attachment Lug



(b) Attachment Lug With an Interference-Fit Bushing

Figure 2-1. Geometries and Nomenclatures of Attachment Lugs

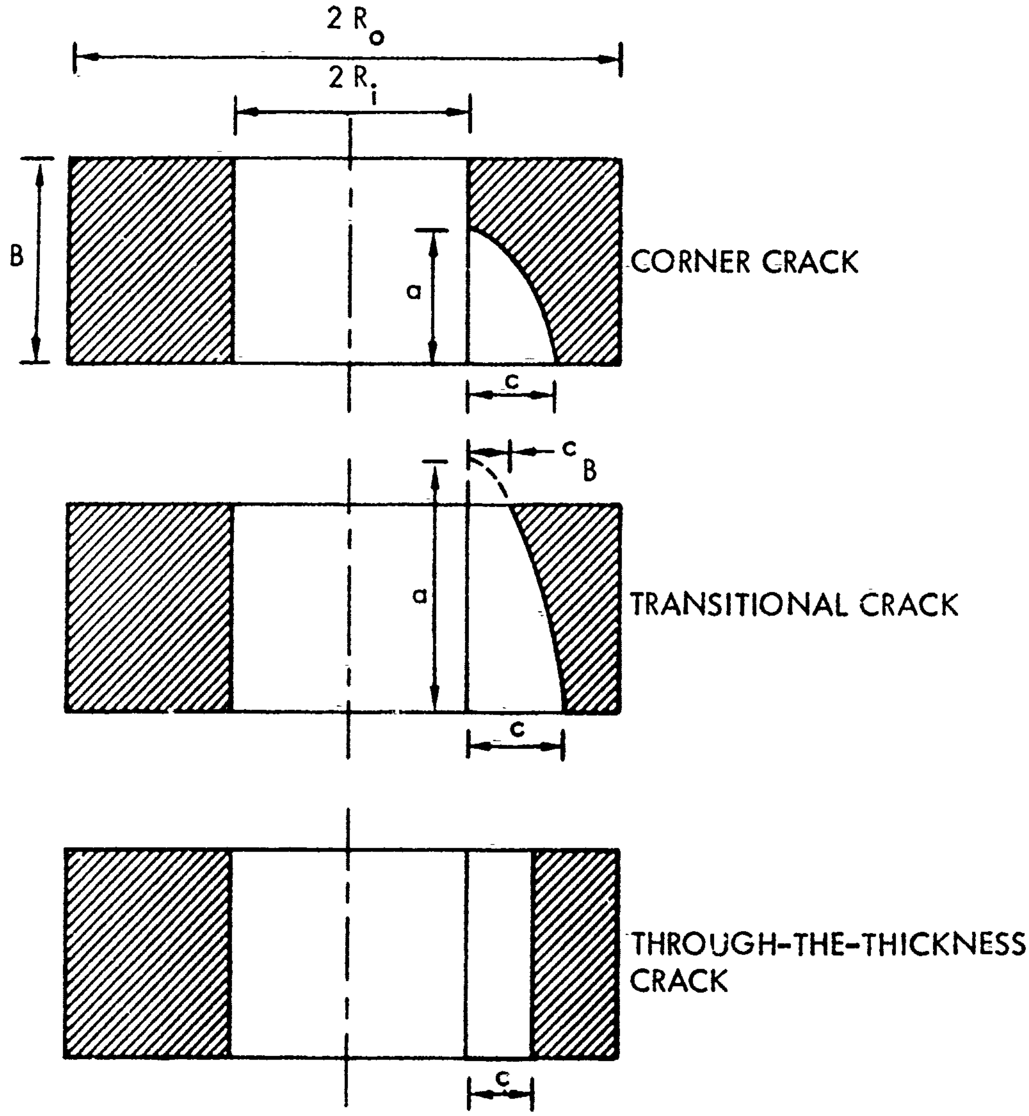


Figure 2-2. Definitions of Crack Lengths

TABLE 2-1. INPUT INSTRUCTIONS FOR CRACK GROWTH ANALYSIS PROGRAM 'LUGRO' FOR ATTACHMENT LUGS

LINE	COLUMN	VARIABLE	TYPE OF VARIABLE	COMMENT
1	1-80	TITLE	ALPHANUMERICAL	
2	1-5	IEQU	INTEGER	
	6-10	LDADN	INTEGER	
	11-15	LLOAD	INTEGER	
	16-20	LSEQ	INTEGER	
3,4,5	(A). IF IEQU = 1, WALKER'S EQUATION IS USED, THEN			
3	1-5	KPOINT	INTEGER	
4	1-10	EFFK(I)	REAL	
	11-20	DADN(I)	REAL	REPEAT 'KPOINT' TIMES
5	1-10	CM	REAL	
	11-20	RC	REAL	
3,4,5,	(B). IF IEQU = 2, FORMAN'S EQUATION IS USED, THEN			
3	1-5	KPOINT	INTEGER	
	6-10	INCFNF	INTEGER	
4	1-10	EFFK(I)	REAL	INPUT ONLY IF INCFNF = 0,
	11-20	DADN(I)	REAL	REPEAT 'KPOINT' TIMES
4*	1-10	FC(I)	REAL	
	11-20	FN(I)	REAL	INPUT ONLY IF INCFNF = 1,
	21-30	EFFK(I)	REAL	REPEAT 'KPOINT-1' TIMES
5	1-10	FKC	REAL	
	11-20	FR	REAL	
	21-30	RC	REAL	
3,4,5	(C). IF IEQU = 3, PARIS' EQUATION IS USED, THEN			
3	1-5	KPOINT	INTEGER	
	6-10	INCPNP	INTEGER	
4	1-10	EFFK(I)	REAL	INPUT ONLY IF INCPNP = 0,
	11-20	DADN(I)	REAL	REPEAT 'KPOINT' TIMES
4*	1-10	PC (I)	REAL	
	11-20	PN(I)	REAL	INPUT ONLY IF INCPNP = 1,
	21-30	EFFK(I)	REAL	REPEAT ' KPOINT-1' TIMES
5	1-10	RC	REAL	

TABLE 2-1. (CONTINUED)

6	1-10	THREKO	REAL	
	11-20	CRITKC	REAL	
	21-30	FTY	REAL	
7	1-5	IRETAR	INTEGER	
	6-10	IMODEL	INTEGER	
8	INPUT ONLY IF IRETAR = 1			
	1-5	IPLANE	INTEGER	
	6-15	EXPM	REAL	EXPM IS INPUT ONLY IF IMODEL = 4
	16-25	XKMXTH	REAL	XKMXTH AND SOS ARE INPUT ONLY
	26-35	SOS	REAL	IF IMODEL = 2
9	1-5	MS	INTEGER	
	6-10	IREAD	INTEGER	
	11-15	ILAYER	INTEGER	
10	1-80	TITLEM	ALPHANUMERICAL	
11	1-10	SRATIO	REAL	
	11-20	HOURM	REAL	
12	1-10	SMAX	REAL	
	11-20	R	REAL	INPUT ONLY IF IREAD=1, REPEAT
	21-30	CPF	REAL	THIS LINE 'ILAYER' TIMES
12*	1-10	SMAX	REAL	
	11-20	SMIN	REAL	INPUT ONLY IF IREAD=2, REPEAT
	21-30	CPF	REAL	THIS LINE 'ILAYER' TIMES
12**	1-10	SMAX	REAL	
	11-20	SMEAN	REAL	INPUT ONLY IF IREAD=3, REPEAT
	21-30	CPF	REAL	THIS LINE 'ILAYER' TIMES
12***	1-10	SMEAN	REAL	
	11-20	SALT	REAL	INPUT ONLY IF IREAD=4, REPEAT
	21-30	CPF	REAL	THIS LINE 'ILAYER' TIMES
12****	1-10	SDEL	REAL	
	11-20	R	REAL	INPUT ONLY IF IREAD=5, REPEAT
	21-30	CPF	REAL	THIS LINE 'ILAYER' TIMES
13		REPEAT LINES 9 TO 12 FOR ALL POSSIBLE MISSIONS, AND THEN INPUT '0' ON COLUMN 5 TO SIGNAL END OF MISSION PROFILES.		
14	1-5	NPASSO	INTEGER	
	6-10	NSEGT	INTEGER	
15	1-5	NFLTS	INTEGER	
	6-10	MISION	INTEGER	REPEAT THIS LINE 'NSEGT' TIMES
16	1-5	ITHRU	INTEGER	
	6-10	METHOD	INTEGER	
	11-15	IBETA	INTEGER	
	16-20	IGFTYP	INTEGER	IGFTYP INPUT ONLY IF METHOD = 2 OR -2

TABLE 2-1. (CONTINUED)

17	1-10	RADIUS	REAL	
	11-20	WIDTH	REAL	
	21-30	THICK	REAL	
18	1-10	CRACKO	REAL	
	11-20	CRACKF	REAL	
19	1-10	AO2CIN	REAL	INPUT ONLY IF ITHRU = 0
20, 21, 22 INPUT ONLY IF IBETA = 1				
20	1-80	TITLEB	ALPHANUMERICAL	
21	1-5	NBPT	INTEGER	
	6-15	B	REAL	
22	1-10	COVERB	REAL	
	11-20	BETATB	REAL	REPEAT 'NBPT' TIMES
20, 21, 22 IF IBETA = -1 THERE ARE NO INPUTS FOR LINES 20, 21, 22				
23, 24, 25 INPUT ONLY IF IBETA = 0				
23	1-5	NSIG	INTEGER	
	6-10	IRSIG	INTEGER	
	11-15	IWRITEA	INTEGER	
24	1-10	TBR	REAL	
	11-20	EL	REAL	
	21-30	EBEL	REAL	INPUT ONLY IF IRSIG = -1 OR
	31-40	DELD	REAL	METHOD = -2
	41-50	POL	REAL	
	51-60	POB	REAL	
25	1-10	YO	REAL	INPUT ONLY IF IRSIG = 0
	11-20	XSIG	REAL	AND METHOD = 2
				REPEAT 'NSIG' TIMES
25*	1-10	YO	REAL	INPUT ONLY IF IRSIG = 1
	11-20	XSIG	REAL	AND METHOD = 2
	21-30	RSIG	REAL	REPEAT 'NSIG' TIMES
25**	11-20	XSIG	REAL	INPUT ONLY IF IRSIG = -1
				AND METHOD = 2
				REPEAT '11(=NSIG)' TIMES
25***	21-30	RSIG	REAL	INPUT ONLY IF IRSIG = 1
				AND METHOD = -2
				REPEAT '11=(NSIG)' TIMES;
				FOR THIS CASE, IN CARD 24
				ONLY TBR AND EBEL NEED TO BE
				INPUT USING THE SAME FORMAT
25**** NO LINE 25 INPUT IF IRSIG = -1 AND METHOD = -2				

TABLE 2-2. INPUT VARIABLES DESCRIPTION

BEFORE DESCRIBING THE INPUT VARIABLES, SOME TERMINOLOGIES, WHICH ARE NOT INPUT VARIALLES, ARE DEFINED HERE, FIRST TO AID THE PREPARATION OF LOAD SPECTRUM AND TO CHOOSE THE OUTPUT OPTION.

BLOCK - ONE COMPLETE PASS THROUGH THE ENTIRE SPECTRUM BEFORE ITS REPETITION. ONE BLOCK CONSISTS OF MULTI-NUMBER OF SEGMENTS.

SEGMENT - FRACTION OF A BLOCK. ONE SEGMENT CONSISTS OF ONE FLIGHT OR MULTIPLE NUMBER OF CONSECUTIVE FLIGHTS OF SAME MISSION.

MISSION - A TYPE OF FLIGHT IN AIRPLANE USAGE.

FLIGHT - ONE COMPLETE PASS THROUGH A GIVEN MISSION. ONE FLIGHT CONSISTS OF MULTI-NUMBER OF LOAD LAYERS.

LAYER - ONE ENTRY IN A MISSION. A LAYER CONSISTS OF A NUMBER OF CONSICUTIVE CYCLES OF SAME STRESS AMPLITUDES.

THE FOLLOWING DESCRIPTION IDENTIFIES ALL OF THE INPUT VARIABLES AND THEIR DEFINITIONS.

TITLE : PROBLEM IDENTIFICATION TITLE.

IEQU : OPTION TO USE DIFFERENT GROWTH RATE EQUATION.
IF IEQU = 1, WALKER'S EQUATION IS USED,
= 2, FORMAN'S EQUATION IS USED,
= 3, PARIS' EQUATION IS USED.

LOADN : OPTION TO PRINT OUT THE INPUT GROWTH RATE DATA.
IF LOADN = 0, PRINT OUT THE GROWTH RATE DATA,
= 1, DO NOT PRINT OUT THE GROWTH RATE DATA.

LLOAD : OPTION TO PRINT OUT THE INPUT LOADING SPECTRUM.
IF LLOAD = 0, PRINT OUT THE INPUT LOADING SPECTRUM,
= 1, DO NOT PRINT OUT THE INPUT LOADING SPECTRUM.

LSEQ : OPTION TO PRINT OUT THE INPUT FLIGHT SEQUENCE OF A BLOCK LOAD SPECTRUM.
IF LSEQ = 0, PRINT OUT THE INPUT FLIGHT SPECTRUM,
= 1, DO NOT PRINT OUT THE INPUT FLIGHT SPECTRUM.

TABLE 2-2. (CONTINUED)

```
KPOINT  : NUMBER OF POINTS ON (DELTA K VS. DA/DN) CURVE. BOTH END
          POINTS ARE INCLUDED. NOUMBER OF LINEAR SEGMENTS USED
          TO REPRESENT THE GROWTH RATE CURVE WILL BE = KPOINT-1.
          NOTE : MAXIMUM KPOINT VALUE IS 30.

EFFK(I) : DELTA K OR EFFECTIVE DELTA K CORRESPONDING TO EACH INPUT
          POINT ( UNIT : KSI*SQRT(INCH) )

DADN(I) : GROWTH RATE DA/DN CORRESPONDING TO EACH DELTA K OR EFFECTIVE
          DELTA K ( UNIT : MICROINCHES )

CM      : CONSTANT 'M' USED IN WALKER'S EQUATION.

RC      : CUT-OFF OF THE MINIMUM APPLIED STRESS RATIO, I.E., IF R<RC, R=RC

INCFNF  : OPTION TO INPUT EITHER ( DELTA K & DA/DN ) PAIRS OR ( CF & NF )
          PAIRS FOR FORMAN'S EQUATION.
          IF INCFNF = 0, INPUT ( DELTA K & DA/DN ) PAIRS,
                    = 1, INPUT ( CF & NF ) PAIRS.
          NOTE : 'CF' & 'NF' ARE CONSTANTS OF FORMAN'S EQUATION.

FC(I)   : CONSTANT 'C' USED IN FORMAN'S EQUATION.
          ( FOR DELTA K IN UNIT KSI*SQRT(INCH) )

FN(I)   : CONSTANT 'N' USED IN FORMAN'S EQUATION.
          ( FOR DELTA K IN UNIT KSI*SQRT(INCH) )

FKC     : KC VALUE TO BE USED IN THE FORMAN'S EQUATION.
          ( UNIT : KSI*SQRT(INCH) )

FR      : R-RATIO OF CONSTANT AMPLITUDE OF INPUT DA/DN DATA.

INCPNP  : OPTION TO INPUT EITHER ( DELTA K & DA/DN ) PAIRS OR ( CF & NF )
          PAIRS FOR PARIS' EQUATION.
          IF INCPNP = 0, INPUT ( DELTA K & DA/DN ) PAIRS,
                    = 1, INPUT ( CF & NF ) PAIRS.
          NOTE : 'CF' & 'NF' ARE CONSTANTS OF PARIS' EQUATION.

PC(I)   : CONSTANT 'C' USED IN PARIS' EQUATION.
          ( FOR DELTA K IN UNIT KSI*SQRT(INCH) )

PN(I)   : CONSTANT 'N' USED IN PARIS' EQUATION.
          ( FOR DELTA K IN UNIT KSI*SQRT(INCH) )
```

TABLE 2-2. (CONTINUED)

```
THREKO  : THRESHOLD DELTA K OF THE MATERIAL USED. WHEN CALCULATED
          DELTA K IS LESS THAN OR EQUAL TO THREKO, NO CRACK GROWTH
          WILL BE CONSIDERED. ( UNIT : KSI*SQRT(INCH) )

CRITKC  : CRITICAL STRESS INTENSITY FACTOR OR FRACTURE TOUGHNESS
          OF THE MATERIAL. ( UNIT : KSI*SQRT(INCH) )

FTY     : TENSILE YIELD STRENGTH OF THE MATERIAL. ( UNIT : KSI )

IRETAR  : OPTION TO CONSIDER SPECTRUM RETARDATION EFFECTS.
          IF IRETAR = 0, NO RETARDATION EFFECT WILL BE CONSIDERED,
                    = 1, SPECTRUM RETARDATION EFFECTS WILL BE CONSIDERED.

IMODEL  : OPTIONS TO USE VARIOUS RETARDATION MODELS.
          IF IMODEL = 1, WILLENBORG MODEL WILL BE USED,
          IF IMODEL = 2, GENERALIZED WILLENBORG MODEL WILL BE USED,
                    = 3, HSU MODEL WILL BE USED,
                    = 4, WHEELER MODEL WILL BE USED.

IPLANE  : OPTIONS TO USE PLANE STRESS OR PLANE STRAIN IN THE CALCULATION
          OF YIELD ZONE.
          IF IPLANE = 1, PLANE STRESS IS USED,
                    = 2, PLANE STRAIN IS USED.

EXPM    : WHEELER'S RETARDATION MODEL EXPONENT M.

XKMXTH  : MAXIMUM THRESHOLD STRESS INTENSITY FACTOR ( UNIT : KSI*SQRT(INCH) )
          (ONLY FOR GENERALIZED WILLENBORG MODEL)

SOS     : OVERLOAD SHUT-OFF RATIO
          (ONLY FOR GENERALIZED WILLENBORG MODEL)

MS      : MISSION NUMBER.

IREAD   : OPTION FOR INPUTTING THE LOAD SPECTRUM.
          IF IREAD = 1, READ IN SMAX, R, & CPF
                   = 2, READ IN SMAX, SMIN, & CPF
                   = 3, READ IN SMAX, SMEAN, & CPF
                   = 4, READ IN SMEAN, SALT, & CPF
                   = 5, READ IN SDEL, R, & CPF

ILAYER  : NUMBER OF LOAD LAYERS IN THE MISSION.

TITLEM  : MISSION IDENTIFICATION TITLE.

SRATIO  : SCALE FACTOR OF THE LOADING SPECTRUM.
```

TABLE 2-2. (CONTINUED)

```
HOURM   : EQUIVALENT FLIGHT HOURS TO THIS MISSION ( IN HOURS )

SMAX    : MAXIMUM AXIAL STRESS OF THE LAYER. ( UNIT : KSI )

SMIN    : MINIMUM AXIAL STRESS OF THE LAYER. ( UNIT : KSI )

R       : AXIAL STRESS RATIO OF THE LAYER, OR R=SMIN/SMAX.

CPF     : NUMBER OF CYCLES OF THE LAYER.

SMEAN   : MEAN AXIAL STRESS OF THE LAYER. ( UNIT : KSI )
          SMEAN = (SMAX+SMIN)/2.0

SALT    : ALTERNATING AXIAL STRESS OF THE LAYER. ( UNIT : KSI )
          SALT = (SMAX-SMIN)/2.0

SDEL    : AXIAL STRESS RANGE OF THE LAYER. ( UNIT : KSI )
          SDEL = SMAX-SMIN

NPASSO  : NUMBER OF BLOCKS OF LOAD SPECTRUM TO BE REPEATED IF FRACTURE
          DOES NOT OCCUR. IF NOT SURE, SET NPASSO = 0, THEN THE PROGRAM
          WILL INTERALLY SET NPASSO = 1,000,000.

NSEGT   : TOTAL NUMBER OF SEGMENTS IN ONE BLOCK OF LOAD SPECTRUM.

NFLTS   : NUMBER OF CONSECUTIVE FLIGHTS OF SAME MISSION IN ONE SEGMENT.

MISSION : MISSION NUMBER OF THE FLIGHT.

ITHRU   : OPTION TO SPECIFY FOR THROUGH-THE-THICKNESS OR PART-THROUGH CRACK.
          IF ITHRU = 0, FOR CORNER CRACK,
                   = 1, FOR THROUGH-THE-THICKNESS CRACK.

METHOD  : METHOD OF STRESS INTENSITY FACTOR CALCULATION.
                   = 1, USE COMPOUNDING METHOD.
                   = 2, USE GREEN FUNCTION METHOD, AND STRESS DISTRIBUTION
                           ALONG CRACK GROWTH PATH WILL BE INPUT
                   =-2, USE GREEN FUNCTION METHOD, AND AUTOMATICALLY
                           CALCULATE STRESS DISTRIBUTION ALONG CRACK
                           GROWTH PATH FROM THE TABLES STORED IN THE
                           PROGRAM, WHICH IS A FUNCTION OF OUTER-TO-
                           INNER RADIUS RATIO OF LUG. IN THE CASE OF
                           LUGS WITH BUSHINGS, THIS OPTION SHOULD BE
                           EXERCISED ONLY WHEN THE RATIO OF LUG OUTER
                           RADIUS TO BUSHING INNER RADIUS(=PIN RADIUS)
                           IS 2.25, SINCE THE SUBROUTINE DIRCAL CONTAINS
                           DATA ONLY FOR THIS LUG-BUSHING CONFIGURATION.
```

TABLE 2-2. (CONTINUED)

IBETA	: OPTION TO INPUT BETA FACTORS DIRECTLY. IF IBETA = 0, SIF WILL BE COMPUTED BY GREEN FUNCTION METHOD OR COMPOUNDING METHOD DEPENDING ON THE VALUE OF THE PARAMETER ' METHOD ' = 1, DIRECT INPUT OF NORMALIZED STRESS INTENSITY FACTORS =-1, AUTOMATICALLY COMPUTE NORMALIZED STRESS INTENSITY FACTORS FROM THE TABLES STORED IN THE PROGRAM, WHICH IS A FUNCTION OF OUTER-TO-INNER RADIUS RATIO OF LUG
IGFTYP	: OPTION TO CHOOSE THE GREEN FUNCTION TYPE (DEFAULT = 1). IF IGFTYP = 1, USE MODIFIED GREEN FUNCTION (FOR LUGS WITH NO BUSHINGS) = 2, USE ORIGINAL GREEN FUNCTION (FOR LUGS WITH BUSHINGS)
RADIUS	: RADIUS OF THE LUG HOLE (UNIT : INCH)
WIDTH	: WIDTH OF THE LUG (=OUTER DIAMETER OF LUG). (UNIT : INCH)
THICK	: THICKNESS OF THE LUG. (UNIT : INCH)
CRACK0	: INITAL CRACK LENGTH 'C'. (UNIT : INCH) NOTE : 'C' REFERS TO THE CRACK LENGTH ON LUG SURFACE.
CRACKF	: FINAL CRACK LENGTH DESIRED IF FRACTURE DOES NOT OCCUR. (UNIT : INCH)
AO2CIN	: INITIAL FLAW SHAPE RATIO OF PART-THROUGH CRACK, A/2C. NOTE : 'A' REFERS TO THE CRACK LENGTH ALONG LUG HOLE WALL.
TITLEB	: TITLE FOR METHOD OF COMPUTATION OF STRESS INTENSITY FACTORS.
NBPT	: NUMBER OF DIRECT NORMALIZED BETA FACTORS TO BE READ IN.
B	: VALUE OF SOME CHARACTERISTIC LENGTH WHICH IS USED (EXAMPLE : LUG HOLE RADIUS) TO NORMALIZE THE CRACK LENGTH. (UNIT : INCH) NOTE : DEFAULT = 1.0 INCH.
COVERB	: VALUE OF C/B FOR WHICH THE BETA FACTOR IS BEING PROVIDED.
BETATB	: VALUE OF BETA FACTOR FOR THE ABOVE COVERB VALUE. BETATB = KI/(GROSS SECTION STRESS*SQRT(PIE*C))
NSIG	: NUMBER OF POINTS AT WHICH THE STRESS DISTRIBUTION IS INPUT. A NEGATIVE VALUE FOR 'NSIG' MEANS THE SAME AS METHOD = -2, IN WHICH CASE THE VALUE OF 'NSIG' IS DEFAULTED TO A VALUE OF 11 - SEE NOTE A)

TABLE 2-2. (CONTINUED)

```
IRSIG   : OPTION TO INCLUDE RESIDUAL STRESSES (SEE NOTE B).
          IF IRSIG = 0, NO RESIDUAL STRESSES,
                   = 1, RESIDUAL STRESSES ARE ALSO PRESENT.
                   =-1, AUTOMATICALLY CALCULATE THE RESIDUAL STRESSES
                        USING THE INPUTS TBR,EL,EBEL,DELD,POL AND POB
                        ('NSIG' IS DEFAULTED TO A VALUE OF 11 IN THIS
                        CASE ALSO - SEE NOTE A)

IWRITEA : OPTION TO WRITE INTERPOLATED GREEN FUNCTION.
          IF IWRITEA = 0, INTERPOLATED GREEN FUNCTION WILL NOT BE PRINTED,
                     = 1, INTERPOLATED GREEN FUNCTION WILL BE PRINTED.

TBR     : BUSHING THICKNESS DIVIDED BY LOADING PIN RADIUS
                   = BUSHING THICKNESS/(LUG INNER RADIUS-BUSHING THICKNESS)

EL      : YOUNG'S MODULUS OF LUG MATERIAL ( UNIT : KSI )

EBEL    : BUSHING-TO-LUG MATERIAL YOUNG'S MODULUS RATIO

DELD    : DIAMETRICAL INTERFERENCE LEVEL ( UNIT : INCH )

POL     : POISSION'S RATIO OF LUG MATERIAL

POB     : POISSION'S RATIO OF BUSHING MATERIAL

YO      : LOCATION AT WHICH THE STRESS IS BEING INPUT. YO = (Y-RI)/RI.

XSIG    : STRESS AT LOCATION YO NORMALIZED BY GROSS SECTION STRESS.
          XSIG = STRESS/GROSS SECTION STRESS.
          GROSS SECTION STRESS = P/(2.0*RO*THICKNESS)
                               = P/(W*THICKNESS)

RSIG    : RESIDUAL STRESS VALUE (SEE NOTE B). ( UNIT = KSI )


NOTE A : THE 11 POINTS CORRESPOND TO DIVIDING THE NET-SECTION OF THE LUG
         BY 10 EQUAL SEGMENTS AND THE 11 'YO=(Y-RI)/RI' VALUES ARE
         AUTOMATICALLY CALCULATED.


NOTE B : THE RESIDUAL STRESS CASE IS APPLICABLE TO THROUGH-THE-THICKNESS
         CRACK PROBLEMS ONLY. HOWEVER FOR CORNER CRACK PROBLEMS INPUT THE
         MAXIMUM STRESS DISTRIBUTION AND A STRESS RATIO SUCH THAT A
         CONSERVATIVE LIFE PREDICTION COULD STILL BE MADE. (SEE SAMPLE
         PROBLEMS 7 AND 8)
```

SECTION III

SAMPLE PROBLEMS

In this section, several sample inputs and outputs of the crack growth program LUGRO are provided to aid the user. Each sample problem consists of problem definition, input and output. Descriptive details are added to the input and output to explain the input variables and to interpret the output. All the sample problems illustrated in this section correspond to specimens tested under this program. Thus, wherever appropriate, the plot of analytical-experimental correlation data is provided.

SAMPLE PROBLEM #1

Material	:	Aluminum
R_o/R_i	:	2.25
R_i	:	0.75
Thickness	:	0.50 Inch
σ_o	:	6 Ksi
R	:	0.1
Crack Type	:	Through-the-Thickness
c_o	:	0.025 Inch

Crack growth analysis for the above lug and crack geometries and loading condition is conducted in this sample problem using Forman's crack growth rate equation and the following given β factors.

No.	$c/(R_o - R_i)$*	β
1	0.0	5.957
2	0.1	3.899
3	0.2	3.126
4	0.3	2.804
5	0.4	2.500
6	0.5	2.422
7	0.6	2.364
8	0.7	2.463
9	0.8	2.646
10	0.9	3.308

*$R_o - R_i = B = 0.9375$ Inch

Analytical-experimental correlation result is given in Figure 3-1.

```
 1: ABPLC46 AND ABPLC93  <----   Line 1:  Title
 2:      2      0      0      1  <----   Line 2:  IEQU = 2, Select Forman Equation
 3:    12      0
 4:          4.0      0.145
 5:          5.0      0.576
 6:          6.0      2.050              Lines 3,4,5,6:  Material Property
 7:          8.0      7.500                    data ΔK vs. da/dN
 8:         10.0     12.900                    ΔK threshold, Kc and Fty
 9:         12.0     18.200
10:         15.0     28.300
11:         20.0     58.900
12:         25.0    134.000
13:         30.0    353.000
14:         40.0   2850.000
15:         45.0   6520.000
16:         60.9        0.1      -0.1
17:          0.0       60.9      74.9
18:      0      0  <----                  Line 7:  IRETAR = 0, no retardation
19:      1      1      1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1   Lines 9,10,11,
21:          1.0        1.0                               12, 13:
22:          6.0        0.1      100.0                   Constant
23:      0                                                Amplitude Loadin
24:      0      1        Line 16:  ITHRU = 1, IBETA = 1   Spectrum Definiti
25:      1      1           Through-the-Thickness crack,
26:      1      0      1 <--    Direct input of β factors
27:      0.7500     3.375      0.5000     Lines 17, 18:  Lug and Crack Geometries
28:      0.0250     .9375
29: DIRECT INPUT OF BETA FACTORS
30:     10    0.9375
31:          0.0      5.957
32:          0.1      3.899
33:          0.2      3.126
34:          0.3      2.804            Lines 20,21, 22:  Input of β factors
35:          0.4      2.500
36:          0.5      2.422
37:          0.6      2.364
38:          0.7      2.463
39:          0.8      2.646
40:          0.9      3.308
```

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.145		
		.15486-09	6.10801
5.000	.578		
		.48242-09	6.83266
6.000	2.050		
		.40772-07	4.36324
8.000	7.500		
		.33672-05	2.23470
10.000	12.900		
		.13327-04	1,63741
12.000	18.200		
		.12825-04	1.65269
15.000	28.300		
		.40172-05	2.08135
20.000	58.900		
		.26501-06	2.98883
25.000	134.000		
		,38220-08	4.30575
30.000	353.000		
		.73701-10	5.46667
40.000	2850.000		
		,93702-07	3.52899
45.000	6520.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	6.000	.600	.100	5.400	100.0

ABPLC46 AND ABPLC93

FORMAN'S EQUATION IS USED IN ANALYSIS

* THRU CRACK EMANATING FROM A LUG HOLE *

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.2500

INITIAL CRACK LENGTH IS .0250 IN.
THE TENSILE YIELD STRENGTH IS 74.90 KSI
THRESHOLD 'K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 60.?00 KSI*SQRT(IN)

TABULAR FUNCTION OF C/B WAS INPUT
WHERE ... B= .93750+00
DIRECT INPUT OF BETA FACTORS

C/B	BETAT
.0000	.5957+01
.1000+00	.3899+01
.2000+00	.3126+01
.3000+00	.2804+01
.4000+00	.2500+01
.5000+00	.2422+01
.6000+00	.2364+01
.7000+00	.2463+01
.8000+00	.2646+01
.9000+00	.3308+01

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	1.4339	8.6037	.00
.0300	10.499	.000674	1.5243	9.1461	10.50
.0350	17.250	.000810	1.6148	9.6895	17.25
.0400	22.858	.000973	1.7052	10.2310	22.86
.0450	27.527	.001169	1.7956	10.7734	27.53
.0500	31.607	.001282	1.8531	11.1188	31.61
.0600	39.111	.001383	1.9289	11.5733	39.11
.0700	46.066	.001492	2.0046	12.0277	46.07
.0800	52.579	.001578	2.0621	12.3726	52.58
.0900	58.803	.001635	2.1013	12.6077	58.80
.1000	64.824	.001686	2.1355	12.8132	64.82
.1200	76.361	.001781	2.1981	13.1883	76.36
.1400	87.283	.001881	2.2606	13.5635	87.28
.1600	97.654	.001976	2.3190	13.9141	97.65
.1800	107.530	.002075	2.3773	14.2639	107.53
.2000	116.959	.002169	2.4312	14.5869	116.96
.2500	138.865	.002397	2.5590	15.3477	138.87
.3000	158.966	.002578	2.6523	15.9136	158.97
.3500	178.057	.002660	2.6941	16.1645	178.06
.4000	196.313	.002918	2.7679	16.6074	196.31
.4500	213.159	.003119	2.8897	17.?781	213.16

.5000	228.403	.003441	3.0069	18.0417	228.40
.6000	254.084	.004346	3.3001	19.8009	254.08
.7000	272.614	.006447	3.7815	22.6892	272.61
.8000	282.154	.014519	4.7043	28.2260	282.15
.9000	284.387	.075019	6.2619	37.5714	284.39

FAILURE DUE TO NET SECTION YIELD (STRESS = 270.01 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

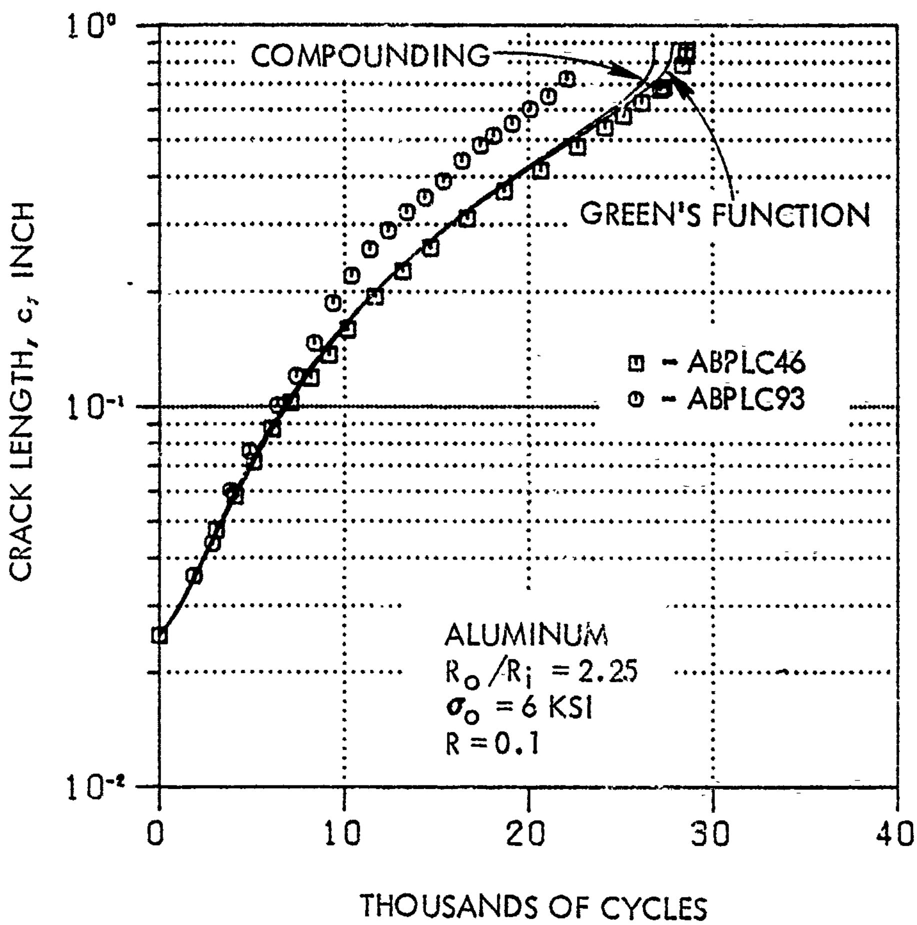


Figure 3-1. Through-the-Thickness Crack Growth Data and Prediction, Aluminum Lug, R_o/R_i=2.25, σ_o=6 ksi, R=0.1

SAMPLE PROBLEM #2

This sample problem is identical to the previous sample problem, except that the β factors are obtained from an already-available table in the program, instead of providing them as input. This is accomplished by specifying the value of 'IBETA' as -1 in the input.

Since the β factors input in the sample problem #1 are essentially the same as those stored in the table, the results of crack growth history are also the same. The slight difference in the solutions (<.15%) is due to computational round-offs.

```
 1: ABPLC46 AND ABPLC93
 2:     2      0      0      1
 3:    12      0
 4:          4.0      0.145
 5:          5.0      0.578
 6:          6.0      2.050
 7:          8.0      7.500
 8:         10.0     12.900
 9:         12.0     18.200
10:         15.0     28.300
11:         20.0     58.900
12:         25.0    134.000
13:         30.0    353.000
14:         40.0   2850.000
15:         45.0   6520.000
16:         60.9        0.1         -0.1
17:          0.0       60.9         74.9
18:     0      0
19:     1      1      1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
21:          1.0        1.0
22:          6.0        0.1        100.0
23:     0
24:     0      1
25:     1      1
26:     1      0     -1
27:     0.7500      3.375      0.5000
28:     0.0250      .9375
```

Line 16: IBETA = -1, Calculate β factors from the tables stored in the program

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (ΔK) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.145		
		.15486-08	6.10801
5.000	.578		
		.48242-09	6.83266
6.000	2.050		
		.40272-07	4.36324
8.000	7.500		
		.33672-05	2.23470
10.000	12.900		
		.13322-04	1.63741
12.000	18.200		
		.12825-04	1.65269
15.000	28.300		
		.40172-05	2.08135
20.000	58.900		
		.26501-06	2.98883
25.000	134.000		
		.38220-08	4.30575
30.000	353.000		
		.73701-10	5.46667
40.000	2850.000		
		.93702-07	3.52899
45.000	6520.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	ΔS (SMAX-SMIN)	CYCLE/PASS
1	6.000	.600	.100	5.400	100.0

```
ABFLC46 AND ABFLC93

        FORMAN'S EQUATION IS USED IN ANALYSIS

       * THRU CRACK EMANATING FROM A LUG HOLE *

        RADIUS OF THE HOLE IS    .7500 IN.
        WIDTH OF THE LUG IS    3.3750 IN.
        THICKNESS OF THE LUG IS      .5000 IN.
        RATIO OF W/D IS    2.2500

        INITIAL CRACK LENGTH IS   .0250 IN.
        THE TENSILE YIELD STRENGTH IS   74.90 KSI
        THRESHOLD DK IS INPUT AS     .000 KSI*SQRT(IN)
        FRACTURE TOUGHNESS KC IS INPUT AS  60.900 KSI*SQRT(IN)

   THE FOLLOWING TABLE IS CALCULATED FROM ALREADY AVAILABLE
 TABULAR BETA FUNCTIONS ( FOR RO/RI=  2.250,AND B=RI=   .7500)
```

C/B	BETAT
.6250-02	.5824+01
.1250-01	.5693+01
.2500-01	.5443+01
.6250-01	.4767+01
.1000+00	.4208+01
.1250+00	.3899+01
.1875+00	.3404+01
.2500+00	.3126+01
.3125+00	.2936+01
.3750+00	.2804+01
.4375+00	.2637+01
.5000+00	.2500+01
.5625+00	.2446+01
.6250+00	.2422+01
.7500+00	.2364+01
.8750+00	.2463+01
.1000+01	.2646+01
.1062+01	.2917+01
.1125+01	.3308+01
.1187+01	.3819+01

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	1.4340	8.6039	.00
.0300	10.497	.000674	1.5243	9.1461	10.50
.0350	17.248	.000810	1.6147	9.6883	17.25
.0400	22.856	.000973	1.7051	10.2205	22.86
.0450	27.525	.001169	1.7954	10.7726	27.53
.0500	31.606	.001282	1.8550	11.1181	31.61
.0600	39.111	.001383	1.9288	11.5731	39.11
.0700	46.066	.001492	2.0047	12.0281	46.07
.0800	52.579	.001578	2.0622	12.3730	52.58
.0900	58.803	.001635	2.1013	12.6079	58.80
.1000	64.824	.001686	2.1355	12.8132	64.82
.1200	76.361	.001781	2.1981	13.1807	76.36

.1400	87.283	.001891	2.2606	13.5635	87.28
.1600	97.654	.001976	2.3190	13.9141	97.65
.1800	107.530	.002075	2.3773	14.2639	107.53
.2000	116.958	.002168	2.4312	14.5874	116.96
.2500	139.862	.002398	2.5581	15.3488	139.86
.3000	158.961	.002578	2.6524	15.9142	158.96
.3500	178.050	.002660	2.6942	16.1653	178.05
.4000	196.303	.002818	2.7681	16.6088	196.30
.4500	213.146	.003119	2.8899	17.3391	213.15
.5000	228.389	.003441	3.0069	18.0417	228.39
.6000	254.071	.004346	3.3001	19.8008	254.07
.7000	272.601	.006447	3.7815	22.6992	272.60
.8000	282.393	.013978	4.6667	28.0004	282.39
.9000	283.931	.116026	6.5886	39.5314	283.93

FAILURE DUE TO NET SECTION YIELD (STRESS = 270.01 PSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

SAMPLE PROBLEM #3

This sample problem also analyzes the same lug and crack geometries and loading condition as the two previous sample problems. However, in this case, the Green's function method is used for computation of stress intensity factors. The following stress distribution (normalized by the gross-section stress, σ_o) is input as a function of $(y - R_i)/R_i$:

No.	$(y - R_i)/R_i$	σ/σ_o
1	0.0000	5.3190
2	0.0625	4.2390
3	0.1875	3.0938
4	0.3125	2.3490
5	0.4375	1.9395
6	0.5625	1.6268
7	0.6875	1.3950
8	0.8125	1.1700
9	0.9375	0.9720
10	1.0625	0.7200
11	1.1875	0.4073

No input is provided for the parameter 'IGFTYP'. The program thus defaults the value of 'IGFTYP' to 1, selecting the modified Green's function to calculate the stress intensity factors. Comparison of results of this sample problem with the previous two sample problems shows a crack growth life difference of about 2%, which arises from slight differences in the stress intensity factors in the two cases.

```
 1: ABPLC46 AND ABPLC93
 2:    2     0     0     1
 3:   12     0
 4:        4.0       0.145
 5:        5.0       0.578
 6:        6.0       2.050
 7:        8.0       7.500
 8:       10.0      12.900
 9:       12.0      18.200
10:       15.0      28.300
11:       20.0      58.900
12:       25.0     134.000
13:       30.0     353.000
14:       40.0    2850.000
15:       45.0    6520.000
16:       60.9         0.1        -0.1
17:        0.0        60.9        74.9
18:    0     0
19:    1     1     1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
21:        1.0         1.0
22:        6.0         0.1       100.0
23:    0
24:    0     1
25:    1     1
26:    1     2     0
27:    0.7500      3.375      0.5000
28:    0.0250      .9375
29:   11     0     0
30:    0.0000     5.3190
31:    0.0625     4.2390
32:    0.1875     3.0938
33:    0.3125     2.3490
34:    0.4375     1.9395
35:    0.5625     1.6268
36:    0.6875     1.3950
37:    0.8125     1.1700
38:    0.9375     0.9720
39:    1.0625     0.7200
40:    1.1875     0.4073
```

Line 16: METHOD = 2, IGFTYP = blank, Use Green's function method, select modified Green's function.

Lines 23, 25: Stress distribution

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.145		
		.15486-08	6.10801
5.000	.578		
		.48242-09	6.83266
6.000	2.050		
		.40272-07	4.36324
8.000	7.500		
		.33672-05	2.23470
10.000	12.900		
		.13322-04	1.63741
12.000	18.200		
		.12825-04	1.65269
15.000	28.300		
		.40172-05	2.08135
20.000	58.900		
		.26501-06	2.98883
25.000	134.000		
		.38220-08	4.30575
30.000	353.000		
		.73701-10	5.46667
40.000	2850.000		
		.93702-07	3.52899
45.000	6520.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	6.000	.600	.100	5.400	100.0

ABPLC46 AND ABPLC93

FORMAN'S EQUATION IS USED IN ANALYSIS

* THRU CRACK EMANATING FROM A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.2500

INITIAL CRACK LENGTH IS .0250 IN.
THE TENSILE YIELD STRENGTH IS 74.90 KSI
THRESHOLD 'K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 60.900 KSI*SQRT(IN)

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	5.319	5.319
.063	4.239	4.239
.188	3.094	3.094
.313	2.349	2.349
.438	1.940	1.940
.563	1.627	1.627
.688	1.395	1.395
.813	1 170	1.170
.938	.972	.972
1.062	.720	.720
1.187	.407	.407

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0047	.0062	5.8242
.0094	.0125	5.7693
.0187	.0250	5.4661
.0469	.0625	4.5984
.0750	.1000	4.1814
.0937	.1250	3.9398
.1406	.1875	3.5187
.1875	.2500	3.1782
.2344	.3125	2.9701
.2813	.3750	2.8063
.3281	.4375	2.6753
.3750	.5000	2.5586
.4219	.5625	2.5003
.4688	.6250	2.4513
.5625	.7500	2.4172
.6563	.8750	2.4794
.7500	1.0000	2.6710
.7969	1.0625	2.9624
.8437	1.1250	3.3401
.8906	1.1875	3.7771

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	1.4240	8.5438	.00
.0300	10.684	.000659	1.5018	9.0110	10.68
.0350	17.666	.000776	1.5797	9.4782	17.67
.0400	23.581	.000915	1.6576	9.9453	23.58
.0450	28.601	.001078	1.7354	10.4125	28.60
.0500	33.023	.001184	1.7941	10.7644	33.02
.0600	41.037	.001312	1.8883	11.3299	41.04
.0700	48.265	.001455	1.9826	11.8954	48.26
.0800	54.871	.001573	2.0586	12.3516	54.87
.0900	61.062	.001658	2.1164	12.6986	61.06
.1000	66.966	.001730	2.1649	12.9893	66.97
.1200	78.100	.001863	2.2505	13.5028	78.10
.1400	88.441	.002005	2.3361	14.0164	88.44
.1600	98.233	.002080	2.3803	14.2817	98.23
.1800	107.681	.002154	2.4232	14.5389	107.68
.2000	116.797	.002234	2.4684	14.8104	116.80
.2500	138.212	.002436	2.5783	15.4701	138.21
.3000	158.028	.002611	2.6692	16.0153	158.03
.3500	176.641	.002762	2.7447	16.4681	176.64
.4000	194.103	.002965	2.8312	16.9871	194.10
.4500	210.205	.003245	2.9362	17.6171	210.20
.5000	224.862	.003578	3.0542	18.3252	224.86
.6000	249.538	.004527	3.3520	20.1118	249.54
.7000	267.492	.006612	3.8120	22.8718	267.49
.8000	276.724	.015052	4.7373	28.4239	276.72
.9000	278.397	.104467	6.4941	38.9646	278.40

FAILURE DUE TO NET SECTION YIELD (STRESS = 270.01 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

SAMPLE PROBLEM #4

Instead of inputting the normalized stress distribution as in the previous sample problem, it can also be obtained from an already-available table in the program. This can be accomplished by specifying 'METHOD' = -2 or using a negative value for 'NSIG'. This is illustrated in the two sets of input data provided for this sample problem. The output data for the two sets of input data will be identical.

```
 1: ABPLC46 AND ABPLC93
 2:     2     0     0     1
 3:    12     0
 4:         4.0     0.145
 5:         5.0     0.578
 6:         6.0     2.050
 7:         8.0     7.500
 8:        10.0    12.900
 9:        12.0    18.200
10:        1[illegible].0    28.300
11:        20.0    58.900
12:        25.0   134.000
13:        30.0   353.000
14:        40.0  2850.000
15:        45.0  6520.000
16:        60.9       0.1       -0.1
17:         0.0      60.9       74.9
18:     0     0
19:     1     1     1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
21:         1.0       1.0
22:         6.0       0.1      100.0
23:     0
24:     0     1
25:     1     1
26:     1    -2     0
27:     0.7500     3.375     0.5000
28:     0.0250     .9375
29:    11     0     0
```

Line 16: METHOD = -2, use Green's function method and calculate stress distribution from the table stored in the program.

```
 1: ABPLC46 AND ABPLC93
 2:     2     0     0     1
 3:    12     0
 4:          4.0      0.145
 5:          5.0      0.578
 6:          6.0      2.050
 7:          8.0      7.500
 8:         10.0     12.900
 9:         12.0     18.200
10:         15.0     28.300
11:         20.0     58.900
12:         25.0    134.000
13:         30.0    353.000
14:         40.0   2850.000
15:         45.0   6520.000
16:         60.9        0.1        -0.1
17:          0.0       60.9        74.9
18:     0     0
19:     1     1     1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
21:          1.0        1.0
22:          6.0        0.1       100.0
23:     0
24:     0     1
25:     1     1
26:     1     2     0
27:     0.7500      3.375      0.5000
28:     0.0250      .9375
29:    -8     0     0
```

Line 16: METHOD = 2, use Green's function method

Line 23: NSIG = -8, calculate stress distribution from the tables stored in the program

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.145		
		.15486-08	6.10901
5.000	.578		
		.48242-09	6.83266
6.000	2.050		
		.40272-07	4.36324
8.000	7.500		
		.33672-05	2.23470
10.000	12.900		
		.13322-04	1.63741
12.000	18.200		
		.12825-04	1.65269
15.000	28.300		
		.40172-05	2.08135
20.000	58.900		
		.26501-06	2.98083
25.000	134.000		
		.38220-08	4.30575
30.000	353.000		
		.73701-10	5.46667
40.000	2850.000		
		.93702-07	3.52899
45.000	6520.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 6 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	6.000	.600	.100	5.400	100.0

ABPLC46 AND ABPLC93

FORMAN'S EQUATION IS USED IN ANALYSIS

* THRU CRACK EMANATING FROM A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.2500

INITIAL CRACK LENGTH IS .0250 IN.
THE TENSILE YIELD STRENGTH IS 74.90 KSI
THRESHOLD ^K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 60.900 KSI*SQRT(IN)

THE FOLLOWING TABLE IS CALCULATED FROM ALREADY AVAILABLE TABULAR
STRESS CONCENTRATION FACTOR VALUES (FOR RO/RI= 2.2500,AND RI= .7500)

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	5.319	5.319
.062	4.239	4.239
.188	3.094	3.094
.313	2.349	2.349
.438	1.940	1.940
.562	1.627	1.627
.687	1.395	1.395
.812	1.170	1.170
.938	.972	.972
1.062	.720	.720
1.187	.407	.407

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0047	.0062	5.8242
.0094	.0125	5.7693
.0187	.0250	5.4661
.0469	.0625	4.5984
.0750	.1000	4.1814
.0937	.1250	3.9398
.1406	.1875	3.5187
.1875	.2500	3.1783
.2344	.3125	2.9702
.2813	.3750	2.8064
.3281	.4375	2.6755
.3750	.5000	2.5589
.4219	.5625	2.5005
.4688	.6250	2.4515
.5625	.7500	2.4173
.6563	.8750	2.4795
.7500	1.0000	2.6711
.7969	1.0625	2.9626
.8437	1.1250	3.3402
.8906	1.1875	3.7772

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	1.4240	8.5438	.00
.0300	10.684	.000659	1.5018	9.0110	10.68
.0350	17.666	.000776	1.5797	9.4782	17.67
.0400	23.581	.000915	1.6576	9.9453	23.58
.0450	28.601	.001078	1.7354	10.4125	28.60
.0500	33.023	.001184	1.7941	10.7644	33.02
.0600	41.037	.001312	1.8883	11.3299	41.04
.0700	48.265	.001455	1.9826	11.8954	48.26
.0800	54.871	.001573	2.0586	12.3517	54.87
.0900	61.062	.001658	2.1165	12.6987	61.06
.1000	66.966	.001730	2.1649	12.9894	66.97
.1200	78.099	.001863	2.2505	13.5031	78.10
.1400	88.440	.002005	2.3361	14.0168	88.44
.1600	98.231	.002080	2.3803	14.2820	98.23
.1800	107.679	.002154	2.4232	14.5393	107.68
.2000	116.794	.002234	2.4685	14.8107	116.79
.2500	138.208	.002436	2.5784	15.4705	138.21
.3000	158.020	.002611	2.6693	16.0160	158.02
.3500	176.634	.002762	2.7449	16.4693	176.63
.4000	194.092	.002966	2.8314	16.9884	194.09
.4500	210.192	.003246	2.9364	17.6184	210.19
.5000	224.846	.003578	3.0544	18.3264	224.85
.6000	249.519	.004528	3.3522	20.1129	249.52
.7000	267.470	.006613	3.8122	22.8730	267.47
.8000	276.700	.015056	4.7375	28.4252	276.70
.9000	278.373	.104484	6.4942	38.9655	278.37

FAILURE DUE TO NET SECTION YIELD (STRESS = 270.01 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

SAMPLE PROBLEM #5

Material	:	Steel
R_o/R_i	:	3.0
R_i	:	0.75 Inch
Thickness	:	0.5 Inch
σ_o	:	14 Ksi
R	:	0.1
Crack Type	:	Corner
c_o	:	0.025 Inch
$a_o/2\ c_o$	:	0.5

This sample problem analyzes and predicts the growth behavior of a corner crack using the Green's function method. 'ITHRU' = 0 specifies that this is a corner crack problem. A value of 0.5 is input for 'A02CIN' to specify that the shape of the initial corner crack is quarter-circular. The output contains three regions of crack growth, namely corner crack growth until the crack breaks through the thickness, transitional crack growth to through-the-thickness crack shape, and subsequent through-the-thickness crack growth until failure.

Analytical-experimental correlation result for this sample problem is given in Figure 3-2.

```
 1: SBPLC55 AND SBPLC79
 2:    2      0      0      1
 3:   13      0
 4:         6.0      0.0911
 5:         8.0      0.1920
 6:        12.0      0.7400
 7:        16.0      1.6600
 8:        20.0      2.9900
 9:        24.0      4.7700
10:        28.0      6.9700
11:        32.0      9.4800
12:        38.0     13.5000
13:        56.0     26.8000
14:        74.0     50.0000
15:        88.0     93.5000
16:        98.0    159.0000
17:       224.7        0.1        -0.1
18:         0.0      224.7       179.7
19:    0      0
20:    1      1      1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:         1.0        1.0
23:        14.0        0.1        100.0
24:    0
25:    0      1
26:    1      1
27:    0      2      0   <------------   Line 16:  ITHRU = 0, corner crack
28:    0.7500      4.500     0.5000
29:    0.0250      1.50
30:         0.5   <-------------------   Line 19:  A02CIN = 0.5, a_o/2c_o = 0.5
31:   11      0      0
32:         0.0      5.145
33:         0.1      4.101
34:         0.3      2.634
35:         0.5      1.854
36:         0.7      1.497
37:         0.9      1.248
38:         1.1      1.065
39:         1.3      0.897
40:         1.5      0.744
41:         1.7      0.558
42:         1.9      0.333
```

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
6.000	.091		
		.18340-06	2.55592
8.000	.192		
		.41021-07	3.27610
12.000	.740		
		.15757-06	2.73452
16.000	1.660		
		.27034-06	2.53981
20.000	2.990		
		.36449-06	2.44007
24.000	4.770		
		.54562-06	2.31313
28.000	6.970		
		.10064-05	2.12941
32.000	9.480		
		.26665-05	1.84825
38.000	13.500		
		.10595-04	1.46899
56.000	26.800		
		.32026-05	1.76621
74.000	50.000		
		.20027-07	2.94524
88.000	93.500		
		.12347-09	4.08182
98.000	159.000		

KC VALUE USED IN FORMAN EQUATION IS 224.700 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000.

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	14.000	1.400	.100	12.600	100.0

SBPLC55 AND SBPLC79

FORMAN'S EQUATION IS USED IN ANALYSIS

* CORNER CRACK AT THE EDGE OF A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 4.5000 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 3.0000

INITIAL CRACK LENGTH IS .0250 IN.
INITIAL FLAW SHAPE A/2C IS .5000
THE TENSILE YIELD STRENGTH IS 179.70 KSI
THRESHOLD ^K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 224.700 KSI*SQRT(IN)

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	5.145	5.145
.100	4.101	4.101
.300	2.634	2.634
.500	1.854	1.854
.700	1.497	1.497
.900	1.248	1.248
1.100	1.065	1.065
1.300	.897	.897
1.500	.744	.744
1.700	.558	.558
1.900	.333	.333

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0075	.0100	5.6337
.0150	.0200	5.5807
.0300	.0400	5.2489
.0750	.1000	4.3038
.1200	.1600	3.8357
.1500	.2000	3.5511
.2250	.3000	3.0610
.3000	.4000	2.6824
.3750	.5000	2.4493
.4500	.6000	2.2703
.5250	.7000	2.1358
.6000	.8000	2.0184
.6750	.9000	1.9506
.7500	1.0000	1.8959
.9000	1.2000	1.8450
1.0500	1.4000	1.8683
1.2000	1.6000	1.9830
1.2750	1.7000	2.1816
1.3500	1.8000	2.4501
1.4250	1.9000	2.7789

PREDICTED PART-THROUGH CORNER CRACK GROWTH HISTORY

GROWTH RATE ALONG THE CRACK PERIPHERY IS VARIABLE

CRACK LENGTH (IN) A	C	AVERAGE A/2C	TIME (PASSES)	GROWTH RATE (IN/PASS) @HOLE	@SURFACE	ALPHA-AXIAL @A	@C	K(MAX) @A	@C	TIME (HOURS)
.02500	.02500	.5000	.000	.000080	.000129	.979	1.162	13.703	16.265	.00
.03000	.03301	.4544	55.919	.000089	.000143	1.111	1.220	15.547	17.085	55.92
.03500	.03942	.4439	95.915	.000125	.000160	1.198	1.280	16.775	17.927	95.92
.04000	.04526	.4418	128.450	.000154	.000180	1.276	1.335	17.862	18.687	128.45
.04500	.05077	.4432	156.197	.000180	.000198	1.342	1.383	18.792	19.364	156.20
.05000	.05604	.4461	180.650	.000204	.000216	1.401	1.426	19.612	19.959	180.65
.06000	.06598	.4547	222.470	.000239	.000238	1.499	1.496	20.979	20.937	222.47
.07000	.07545	.4639	258.134	.000280	.000266	1.581	1.548	22.135	21.677	258.13
.08000	.08465	.4725	289.282	.000321	.000295	1.665	1.521	23.303	22.696	289.28
.09000	.09373	.4801	316.867	.000363	.000329	1.741	1.683	24.373	23.568	316.87
.10000	.10264	.4871	341.669	.000403	.000359	1.811	1.737	25.352	24.316	341.67
.12000	.11956	.5018	384.498	.000167	.000395	1.931	1.823	27.035	25.515	384.50
.14000	.13594	.5149	421.682	.000538	.000440	2.040	1.879	28.563	26.309	421.68
.16000	.15148	.5281	454.590	.000608	.000472	2.136	1.922	29.897	26.903	454.59
.18000	.16637	.5410	484.271	.000674	.000502	2.225	1.973	31.151	27.626	484.27
.20000	.18079	.5531	511.399	.000737	.000531	2.307	2.015	32.294	28.208	511.40
.25000	.21367	.5850	569.984	.000853	.000561	2.469	2.083	34.561	29.157	569.98
.30000	.24492	.6124	621.698	.000967	.000604	2.605	2.133	36.475	29.868	621.70
.35000	.27462	.6372	668.557	.001067	.000634	2.719	2.168	38.062	30.348	668.56
.40000	.30315	.6597	711.947	.001152	.000658	2.814	2.185	39.403	30.585	711.95
.45000	.33076	.6802	752.680	.001227	.000678	2.900	2.226	40.595	31.164	752.68
.50000	.35788	.6986	791.233	.001297	.000703	3.016	2.243	42.229	31.399	791.23

TRANSITIONAL CRACK GROWTH BETWEEN
THE END OF PART-THRU CRACK AND UNIFORM THRU CRACK

CRACK LENGTH (IN) B	C	C/B	TIME (PASSES)	GROWTH RATE (IN/PASS) @BACK	@FRONT	ALPHA-AXIAL @B	@C	K(MAX) B.	C.	TIME (HOURS)
.15683	.35788	2.2820	791.233	.001297	.000703	3.016	2.243	42.229	31.399	791.23
.23059	.40788	1.7689	848.106	.005865	.000761	6.155	2.310	86.169	32.340	848.11
.43470	.43470	1.0000	882.910	.001067	.001067	2.691	2.691	37.675	37.675	882.91

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.4347	882.910	.001067	2.6911	37.6749	882.91
.4847	929.271	.001090	2.7196	38.0741	929.27
.5347	974.663	.001113	2.7466	38.4529	974.66
.6347	1062.651	.001160	2.8033	39.2459	1062.65
.7347	1145.941	.001241	2.8960	40.5435	1145.94
.8347	1223.336	.001343	3.0187	42.2612	1223.34
.9347	1294.476	.001468	3.1696	44.3744	1294.48
1.0347	1359.088	.001627	3.3635	47.0894	1359.09
1.1347	1416.206	.001874	3.6512	51.1172	1416.21
1.2347	1464.183	.002294	4.0889	57.2444	1464.18
1.3347	1499.808	.003320	4.9071	68.6989	1499.81

FAILURE DUE TO NET SECTION YIELD (STRESS = 190.56 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

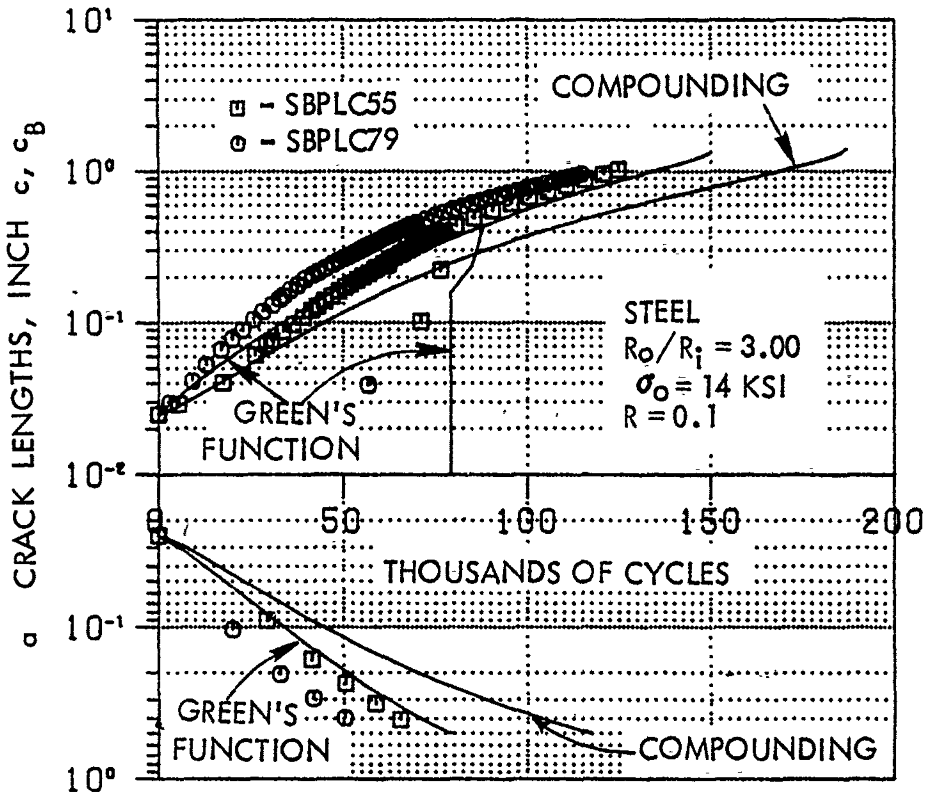


Figure 3-2. Corner Crack Growth Data and Prediction, Steel Lug, R_o/R_i=3.0, σ_o=14 KSI, R=0.1

SAMPLE PROBLEM #6

This sample problem illustrates the use of compounding method to analyze a crack problem by specifying 'METHOD' = 1. The lug and crack geometries and loading condition are the same as the sample problem #5. In the output, only one crack length (the front surface crack length c) is printed. Since a/c ratio is assumed as constant in the compounding method, the crack length along the lug hole wall or the back surface crack length can be calculated using the front surface crack length, a/c ratio and the thickness of the lug.

The computed solution using the compounding method is also included in Figure 3-2 (sample problem #5).

```
 1: SBPLC55 AND SBPLC79
 2:     2     0     0     1
 3:    13     0
 4:         6.0    0.0911
 5:         8.0    0.1920
 6:        12.0    0.7400
 7:        16.0    1.6600
 8:        20.0    2.9900
 9:        24.0    4.7700
10:        28.0    6.9700
11:        32.0    9.4800
12:        38.0   13.5000
13:        56.0   26.8000
14:        74.0   50.0000
15:        88.0   93.5000
16:        98.0  159.0000
17:       224.7       0.1       -0.1
18:         0.0     224.7      179.7
19:     0     0
20:     1     1     1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:         1.0       1.0
23:        14.0       0.1      100.0
24:     0
25:     0     1
26:     1     1
27:     0     1     0
28:    0.7500     4.500     0.5000
29:    0.0250      1.50
30:         0.5
```

Line 16: ITHRU = 0, METHOD = 1, corner crack, use compounding method

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
6.000	.091		
		.18340-06	2.55592
8.000	.192		
		.41021-07	3.27610
12.000	.740		
		.15757-06	2.73452
16.000	1.660		
		.27034-06	2.53981
20.000	2.990		
		.36449-06	2.44007
24.000	4.770		
		.54562-06	2.31313
28.000	6.970		
		.10064-05	2.12941
32.000	9.480		
		.26665-05	1.84825
38.000	13.500		
		.10595-04	1.46899
56.000	26.800		
		.32026-05	1.76621
74.000	50.000		
		.20027-07	2.94524
88.000	93.500		
		.12347-09	4.08182
98.000	159.000		

KC VALUE USED IN FORMAN EQUATION IS 224.700 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	14.000	1.400	.100	12.600	100.0

SBPLC55 AND SBPLC79

FORMAN'S EQUATION IS USED IN ANALYSIS

* CORNER CRACK AT THE EDGE OF A LUG HOLE *
COMPOUNDED SOLUTION METHOD IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 4.5000 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 3.0000

INITIAL CRACK LENGTH IS .0250 IN.
INITIAL FLAW SHAPE A/2C IS .5000
THE TENSILE YIELD STRENGTH IS 179.70 KSI
THRESHOLD [illegible] IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 224.700 KSI*SQRT(IN)

COMPUTED S.I.F. USING COMPOUNDING METHOD

C	C/RI	BETA	ALPHA
.0015	.0020	3.7406	.2568
.0045	.0060	3.7011	.4401
.0075	.0100	3.6626	.5622
.0105	.0140	3.6250	.6584
.0150	.0200	3.5705	.7751
.0225	.0300	3.4843	.9264
.0300	.0400	3.4033	1.0448
.0375	.0500	3.3274	1.1421
.0450	.0600	3.2561	1.2243
.0600	.0800	3.1261	1.3573
.0750	.1000	3.0111	1.4616
.0900	.1200	2.9090	1.5468
.1050	.1400	2.8180	1.6185
.1200	.1600	2.7365	1.6802
.1350	.1800	2.6633	1.7344
.1500	.2000	2.5971	1.7828
.1800	.2400	2.4821	1.8665
.2100	.2800	2.3851	1.9373
.2400	.3200	2.3016	1.9985
.2700	.3600	2.2283	2.0523
.3000	.4000	2.1632	2.1000
.3750	.5000	2.0265	2.1996
.4500	.6000	1.9181	2.2806
.5250	.7000	1.8318	2.3525
.6000	.8000	1.7647	2.4228
.7500	1.0000	1.6817	2.5814
.9000	1.2000	1.6653	2.8003
1.0500	1.4000	1.7293	3.1409
1.2000	1.6000	1.9287	3.7448
1.3500	1.8000	2.5061	5.1611
1.4250	1.9000	3.3983	7.1902

PREDICTED CORNER CRACK GROWTH HISTORY
(USING COMPOUNDING METHOD WHERE A/C IS CONSTANT)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)

.0250	.000	.000000	.9658	13.5218	.00
.0300	75.040	.000096	1.0448	14.6275	75.04
.0350	122.917	.000113	1.1097	15.5353	122.92
.0400	163.774	.000131	1.1695	16.3727	163.77
.0450	199.336	.000150	1.2243	17.1399	199.34
.0500	231.178	.000164	1.2686	17.7604	231.18
.0600	286.420	.000198	1.3573	19.0015	286.42
.0700	333.703	.000225	1.4268	19.9756	333.70
.0800	375.549	.000253	1.4900	20.8603	375.55
.0900	413.148	.000279	1.5468	21.6555	413.15
.1000	447.552	.000302	1.5946	22.3243	447.55
.1200	509.297	.000346	1.6802	23.5231	509.30
.1400	564.114	.000384	1.7506	24.5081	564.11
.1600	613.959	.000419	1.8107	25.3502	613.96
.1800	659.868	.000453	1.8665	26.1310	659.87
.2000	702.666	.000482	1.9137	26.7915	702.67
.2500	799.722	.000548	2.0164	28.2301	799.72
.3000	886.333	.000606	2.1000	29.4004	886.33
.3500	965.677	.000654	2.1664	30.3296	965.68
.4000	1039.575	.000699	2.2266	31.1722	1039.57
.4500	1109.081	.000740	2.2806	31.9281	1109.08
.5000	1175.070	.000776	2.3295	32.5996	1175.07
.6000	1298.082	.000850	2.4228	33.9190	1298.08
.7000	1410.141	.000935	2.5285	35.3991	1410.14
.8000	1511.630	.001036	2.6543	37.1607	1511.63
.9000	1602.791	.001158	2.8003	39.2039	1602.79
1.0000	1682.752	.001343	3.0273	42.3826	1682.75
1.1000	1750.649	.001602	3.3422	46.7903	1750.65
1.2000	1806.708	.001965	3.7448	52.4270	1806.71
1.3000	1846.930	.003007	4.6890	65.6457	1846.93
1.4000	1865.862	.007558	6.5138	91.1932	1865.86

FAILURE DUE TO NET SECTION YIELD (STRESS = 315.00 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

SAMPLE PROBLEM #7

Material	:	Aluminum
R_o/R_i	:	2.25
R_i	:	0.75 Inch
Thickness	:	0.5 Inch
Crack Type	:	Through-the-Thickness
c_o	:	0.025 Inch
Loading	:	As Described Below

This sample problem illustrates the analysis of a through-the-thickness crack problem with residual stress. In this case, the lug is loaded with a far-field stress (σ_o) of 15 ksi and a stress ratio (R) of 0.5. For this loading condition, the uncracked lug undergoes plastic yielding. An elasto-plastic stress analysis was conducted to obtain the stress distribution at the maximum and minimum (corresponding to R = 0.5) stress levels. The resulting stress distributions are presented in Figure 3-3. The stress distribution at the minimum stress level is considered as the residual stress and the difference in the stress distributions between maximum and minimum stress levels is considered as the alterating stress. This stress distribution, without normalizing by the far-field stress (σ_o), is specified as shown in the input data. Since the stress distribution is not normalized, values of 1.0 and 0.0 are input for 'SMAX' and 'R' in the spectrum layer input.

Comparison of analytical and experimental results is presented in Figure 3-4. The present output data correspond to the curve labelled PLASTIC STRESS.

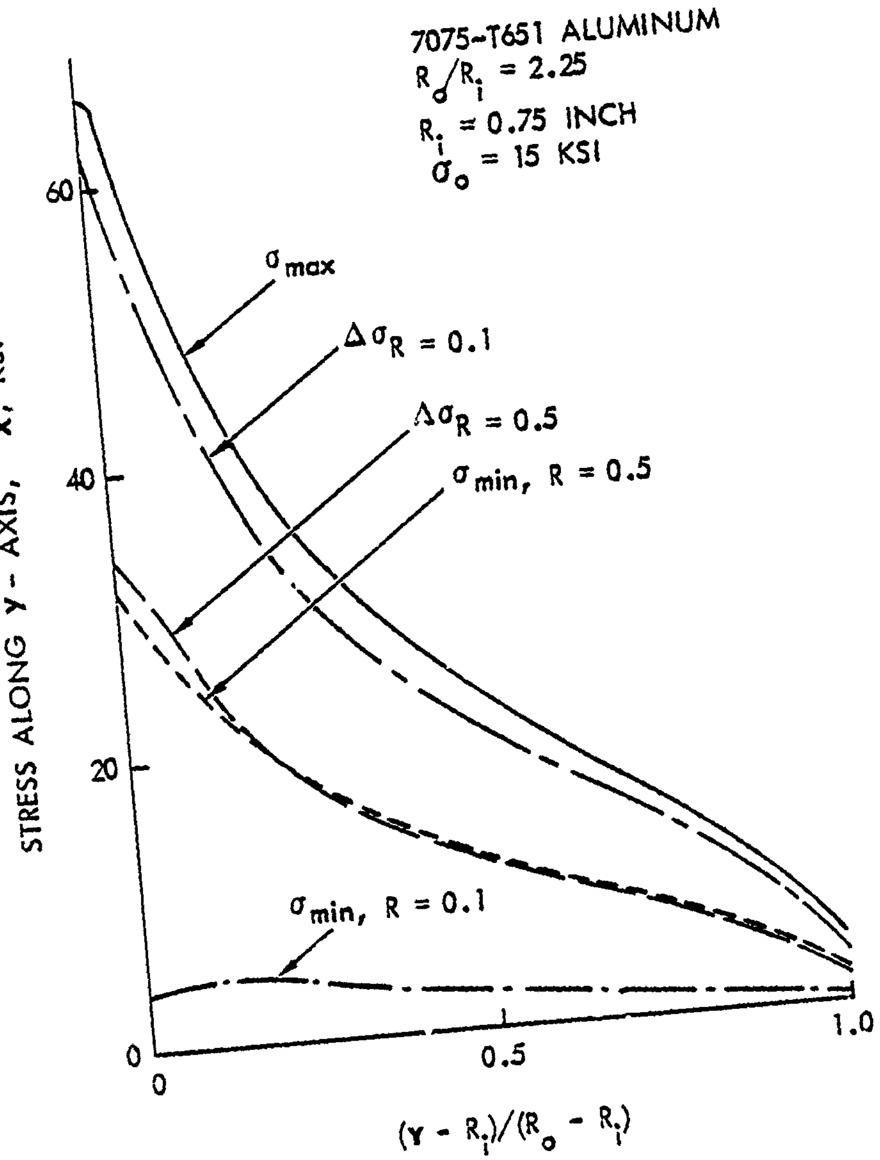


Figure 3-3. Stress Distribution Along y-Axis for an Aluminum Lug with R_o/R_i = 2.25

```
 1: ABPLC49 AND AB?LC79
 2:     2      0      0      1
 3:    12      0
 4:          1.5     0.0415
 5:          2.0      0.125
 6:          3.0      0.249
 7:          4.0      0.876
 8:          5.0      2.650
 9:          7.0      9.190
10:          9.0     15.900
11:         11.0     25.100
12:         13.0     45.100
13:         15.0     95.900
14:         19.0    533.000
15:         23.0   2080.000
16:         60.9        0.5        -0.1
17:          0.0       60.9        74.9
18:     0      0
19:     1      1      1
20: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 15 KSI AND R=0.5
21:          1.0        1.0
22:          1.0        0.0       100.0 <-- Line 12:  SMAX = 1.0, R = 0.0
23:     0
24:     0      1
25:     1      1
26:     1      2      0 <-------------- Line 16:  ITHRU = 1, through-the-
27:     0.7500      3.375      0.5000             thickness crack
28:     0.0250     0.9375
29:    11      1      0 <-------------- Line 23:  IRSIG = 1, residual stress
30:     0.0000      34.70      32.10              present
31:     0.0625      30.97      28.22
32:     0.1875      22.84      22.54
33:     0.3125      17.70      18.26
34:     0.4375      14.79      15.40
35:     0.5625      12.46      12.86
36:     0.6875      10.73      11.06      Line 25*:  Stress distribution
37:     0.8125       9.02       9.30                 (cyclic and residual
38:     0.9375       7.53       7.80                 stresses)
39:     1.0625       5.66       5.95
40:     1.1875       3.31       3.61
```

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
1.500	.041		
		.23028-06	3.77221
2.000	.125		
		.11639-05	1.611[illegible]9
3.000	.249		
		.64571-07	4.24358
4.000	.876		
		.30358-07	4.78799
5.000	2.650		
		.26041-06	3.45262
7.000	9.190		
		.61628-05	1.82663
9.000	15.900		
		.67181-05	1.78736
11.000	25.100		
		.51509-06	2.85840
13.000	45.100		
		.93516-08	4.42131
15.000	95.900		
		.13422-09	5.98842
19.000	533.000		
		.35377-08	4.87726
23.000	2080.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .5000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 15 KSI AND R=0.5
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	1.000	.000	.000	1.000	100.0

ABPLC49 AND ABPLC79

FORMAN'S EQUATION IS USED IN ANALYSIS

* THRU CRACK EMANATING FROM A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.2500

INITIAL CRACK LENGTH IS .0250 IN.
THE TENSILE YIELD STRENGTH IS 74.90 KSI
THRESHOLD ^K IS INPUT AS .000 KSI*S RT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 60.900 KSI*SQRT(IN)

A FAR FIELD STRESS OF 1 KSI AND A STRESS RATIO OF 0.1
IS ASSUMED IN THE CALCULATION OF FOLLOWING TABLE

EFFECTIVE UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	RESIDUAL STRESS	STRESS/UNIT LOAD	EFFECTIVE MAX. & MIN. STRESSES	
.000	32.100	34.700	66.800	35.570
.063	28.220	30.970	59.190	31.317
.188	22.540	22.840	45.380	24.824
.313	18.260	17.700	35.960	20.030
.438	15.400	14.790	30.190	16.879
.563	12.860	12.460	25.320	14.106
.688	11.060	10.730	21.790	12.133
.813	9.300	9.020	18.320	10.202
.938	7.800	7.530	15.330	8.553
1.062	5.950	5.660	11.610	6.516
1.187	3.610	3.310	6.920	3.941

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	K(MAX)	K(MIN)	^K	R	BETA(MAX)
.0047	.0062	8.9241	4.7503	4.1738	.5323	73.5392
.0094	.0125	12.5704	6.6890	5.8814	.5321	73.2467
.0187	.0250	17.0359	9.0587	7.9772	.5317	70.1921
.0469	.0625	23.5324	12.4844	11.0480	.5305	61.3227
.0750	.1000	27.6467	14.6906	12.9562	.5314	56.9559
.0937	.1250	29.3956	15.6561	13.7394	.5326	54.1653
.1406	.1875	32.7455	17.5772	15.1683	.5368	49.2658
.1875	.2500	34.6087	18.6972	15.9115	.5402	45.0930
.2344	.3125	36.6388	19.8959	16.7429	.5430	42.6993
.2813	.3750	38.2706	20.8655	17.4051	.5452	40.7140
.3281	.4375	39.6665	21.6798	17.9868	.5466	39.0688
.3750	.5000	40.7671	22.3209	18.4462	.5475	37.5594
.4219	.5625	42.4092	23.2441	19.1651	.5481	36.8377
.4688	.6250	43.9716	24.1155	19.8561	.5484	36.2349
.5625	.7500	47.7261	26.1854	21.5407	.5487	35.9021
.6563	.8750	53.0390	29.1358	23.9032	.5493	36.9390
.7500	1.0000	61.2496	33.6856	27.5640	.5500	39.9023
.7969	1.0625	70.1871	38.6239	31.5632	.5503	44.3596
.8437	1.1250	81.6570	44.9706	36.6864	.5507	50.1547

.8906	1.1875	95.1847	52.4747	42.7100	.5513	56.9043

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	18.4795	18.4795	.00
.0300	3.422	.002048	19.6345	19.6345	3.42
.0350	5.681	.002396	20.7894	20.7894	5.68
.0400	7.617	.002779	21.9444	21.9444	7.62
.0450	9.280	.003237	23.0993	23.0993	9.28
.0500	10.718	.003718	23.9896	23.9896	10.72
.0600	13.059	.004925	25.4524	25.4524	13.06
.0700	14.862	.006263	26.9153	26.9153	14.86
.0800	16.283	.007819	28.1131	28.1131	16.28
.0900	17.445	.009393	29.0458	29.0458	17.44
.1000	18.422	.011066	29.8422	29.8422	18.42
.1200	19.956	.015006	31.2716	31.2716	19.96
.1400	21.088	.020350	32.7009	32.7009	21.09
.1600	21.992	.023864	33.5156	33.5156	21.99
.1800	22.766	.027855	34.3106	34.3106	22.77
.2000	23.426	.032766	35.1501	35.1501	23.43
.2500	24.663	.048044	37.1827	37.1827	24.66
.3000	25.558	.063705	38.8290	38.8290	25.56
.3500	26.257	.079335	40.1801	40.1801	26.26
.4000	26.812	.100919	41.6429	41.6429	26.81
.4500	27.237	.134116	43.3466	43.3466	27.24
.5000	27.551	.184854	45.2231	45.2231	27.55
.6000	27.876	.429235	49.8512	49.8512	27.88
.7000	28.342	.000000	56.8706	56.8706	28.34

** K(MAX) REACHED KC WHICH HAS BEEN INPUT AS 60.900

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

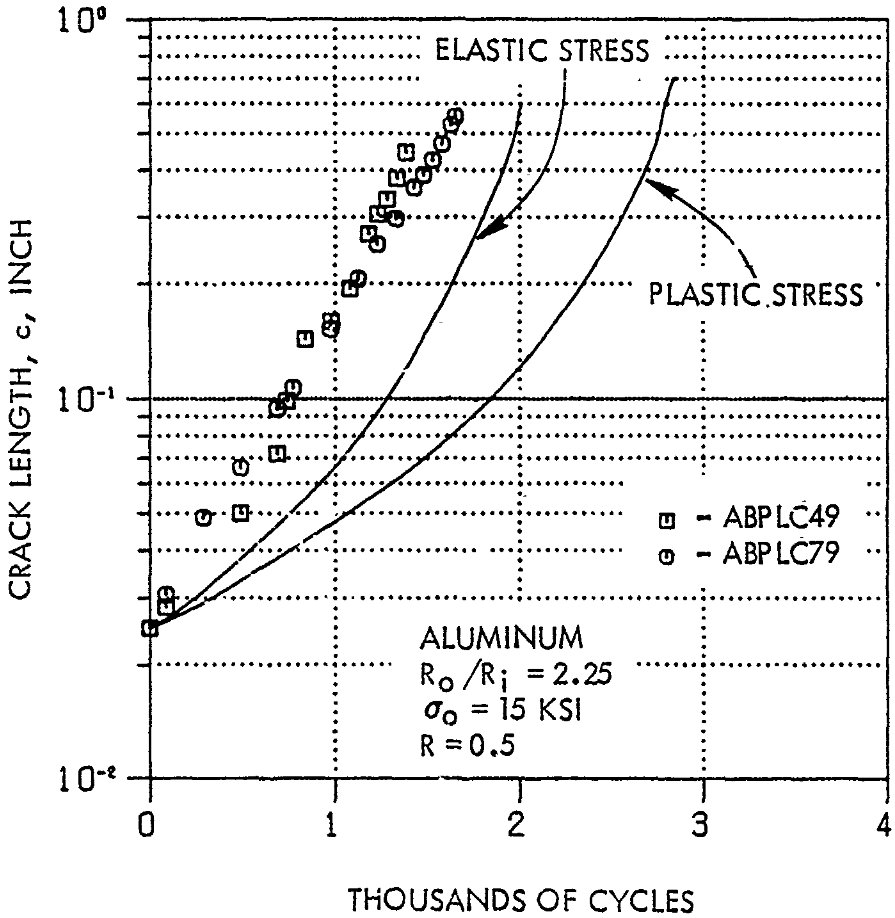


Figure 3-4. Through-the-Thickness Crack Growth Data and Prediction, Aluminum Lug, R_o/R_i=2.25, σ_o = 15 ksi, R=0.5

SAMPLE PROBLEM #8

In the input instruction (Section II), Note B states that the residual stress case is applicable to the through-the-thickness crack problem only. Sample problem #7 illustrated the analysis of a through-the-thickness crack problem with residual stress. Note B also states that, for analyzing corner crack problems with residual stress, input the maximum stress distribution and a stress ratio such that a conservative life prediction can still be made. Using the data of sample problem #7, the maximum stress distribution and a conservative R are calculated as follows:

$(y-R_i)/R_i$	σ_{alt} (KSI)	σ_{res} (KSI)	σ_{max} $(= \sigma_{alt.} + \sigma_{res})$ (KSI)	$R_{eff} = \frac{\sigma_{res}}{\sigma_{max}}$
0.0000	34.70	32.10	66.80	0.48054
0.0625	30.97	28.22	59.19	0.47677
0.1875	22.84	22.54	45.38	0.49669
0.3125	17.70	18.26	35.96	0.50779
0.4375	14.79	15.40	30.19	0.51010
0.5625	12.46	12.86	25.32	0.50790
0.6875	10.73	11.06	21.79	0.50757
0.8125	9.02	9.30	18.32	0.50764
0.9375	7.53	7.80	15.33	0.50881
1.0625	5.66	5.95	11.61	0.51249
1.1875	3.31	3.61	6.92	0.52168

A conservative R will be the minimum value of R_{eff} in the above table. The maximum stress distribution and the conservative R are then specified as shown in the input data.

Also note in the output data of sample problems 1 through 6, the failures are due to net-section yielding. In sample problems 7 and 8, the failures are due to the exceedence of critical stress intensity factor (fracture toughness) values.

Predicted and experimental data are compared in Figure 3-5. The curve labelled PLASTIC STRESS corresponds to present output data.

```
 1:  ABPLC35 ABD  ABPLC37
 2:     2      0      0      1
 3:    12      0
 4:          1.5     0.0415
 5:          2.0      0.125
 6:          3.0      0.249
 7:          4.0      0.876
 8:          5.0      2.650
 9:          7.0      9.190
10:          9.0     15.900
11:         11.0     25.100
12:         13.0     45.100
13:         15.0     95.900
14:         19.0    533.000
15:         23.0   2080.000
16:         60.9        0.5        -0.1
17:          0.0       60.9        74.9
18:     0      0
19:     1      1      1
20:  CONSTANT AMPLITUDE WITH SIGMA(MAX)= 15 KSI AND R=0.5
21:          1.0        1.0
22:          1.0    0.47677      100.0 <--- Line 12:  SMAX = 1.0, R = 0.47677
23:     0
24:     0      1
25:     1      1
26:     0      2      0 <------------------ Line 16:  ITHRU = 0, corner crack
27:     0.7500      3.375     0.5000
28:     0.0250      .9375
29:          0.5
30:    11      0      0
31:     0.0000      66.80
32:     0.0625      59.19
33:     0.1875      45.38
34:     0.3125      35.96
35:     0.4375      30.19
36:     0.5625      25.32         Lines 23, 25:  Stress distribution
37:     0.6875      21.79                        (no residual stress)
38:     0.8125      18.32
39:     0.9375      15.33
40:     1.0625      11.61
41:     1.1875       6.92
```

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
1.500	.041		
		.26028-06	3.77721
2.000	.125		
		.11639-05	1.61138
3.000	.249		
		.64571-07	4.24358
4.000	.876		
		.30358-07	4.78799
5.000	2.650		
		.26041-06	3.45262
7.000	9.190		
		.61628-05	1.82663
9.000	15.900		
		.67181-05	1.78736
11.000	25.100		
		.51509-06	2.85840
13.000	45.100		
		.93516-08	4.42131
15.000	95.900		
		.13422-09	5.98842
19.000	533.000		
		.35377-08	4.87726
23.000	2080.000		

KC VALUE USED IN FORMAN EQUATION IS 60.900 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .5000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 15 KSI AND R=0.5
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	1.000	.477	.477	.523	100.0

ABPLC35 ABD ABPLC37

FORMAN'S EQUATION IS USED IN ANALYSIS

* CORNER CRACK AT THE EDGE OF A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.2500

INITIAL CRACK LENGTH IS .0250 IN.
INITIAL FLAW SHAPE A/2C IS .5000
THE TENSILE YIELD STRENGTH IS 74.90 KSI
THRESHOLD DK IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 60.900 KSI*SQRT(IN)

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	66.800	66.800
.063	59.190	59.190
.188	45.380	45.380
.313	35.960	35.960
.438	30.190	30.190
.563	25.320	25.320
.688	21.790	21.790
.813	18.320	18.320
.938	15.330	15.330
1.062	11.610	11.610
1.187	6.920	6.920

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0047	.0062	73.5392
.0094	.0125	73.2467
.0187	.0250	70.1921
.0469	.0625	61.3227
.0750	.1000	56.9559
.0937	.1250	54.1653
.1406	.1875	49.2658
.1875	.2500	45.0930
.2344	.3125	42.6983
.2813	.3750	40.7140
.3281	.4375	39.0688
.3750	.5000	37.5594
.4219	.5625	36.8377
.4688	.6250	36.2349
.5625	.7500	35.9021
.6563	.8750	36.9390
.7500	1.0000	39.9023
.7969	1.0625	44.3594
.8437	1.1250	50.1547
.8906	1.1875	56.9043

PREDICTED PART-THROUGH CORNER CRACK GROWTH HISTORY

GROWTH RATE ALONG THE CRACK PERIPHERY IS VARIABLE

CRACK LENGTH (IN) A	C	AVERAGE A/2C	TIME (PASSES)	GROWTH RATE (IN/PASS) @HOLE	@SURFACE	ALPHA-AXIAL @A	@C	K(MAX) @A	@C	TIME (HOURS)
.02500	.02500	.5000	.000	.000716	.001072	12.708	14.789	12.708	14.789	.00
.03000	.03202	.4684	6.079	.000822	.001155	14.211	15.577	14.211	15.577	6.08
.03500	.03803	.4602	10.817	.001055	.001267	15.268	16.316	15.268	16.316	10.82
.04000	.04366	.4581	14.892	.001227	.001391	16.256	16.952	16.256	16.952	14.89
.04500	.04903	.4589	18.488	.001390	.001494	17.117	17.594	17.117	17.594	18.49
.05000	.05429	.4605	21.731	.001541	.001621	17.895	18.303	17.895	18.303	21.73
.06000	.06461	.4644	27.426	.001756	.001812	19.253	19.531	19.253	19.531	27.43
.07000	.07474	.4683	32.375	.002021	.002047	20.423	20.546	20.423	20.546	32.38
.08000	.08461	.4728	36.748	.002287	.002257	21.605	21.416	21.605	21.416	36.75
.09000	.09418	.4778	40.660	.002556	.002446	22.665	22.163	22.665	22.163	40.66
.10000	.10355	.4827	44.217	.002812	.002635	23.632	22.962	23.632	22.962	44.22
.12000	.12167	.4931	50.472	.003197	.002897	25.332	24.306	25.332	24.306	50.47
.14000	.13932	.5024	55.956	.003647	.003219	26.809	25.318	26.809	25.318	55.96
.16000	.15646	.5113	60.865	.004074	.003491	28.179	26.129	28.179	26.129	60.86
.18000	.17291	.5205	65.309	.004501	.003702	29.439	26.774	29.439	26.774	65.31
.20000	.18876	.5298	69.384	.004907	.003888	30.576	27.301	30.576	27.301	69.38
.25000	.22628	.5524	78.262	.005632	.004227	33.014	28.998	33.014	28.998	78.26
.30000	.26286	.5707	85.980	.006478	.004739	35.035	30.359	35.035	30.359	85.98
.35000	.29863	.5860	92.887	.007239	.005180	36.789	31.511	36.789	31.511	92.89
.40000	.33369	.5994	99.182	.007943	.005570	38.333	32.509	38.333	32.509	99.18
.45000	.36809	.6113	104.997	.008598	.005915	39.703	33.360	39.703	33.360	105.00
.50000	.40225	.6215	110.408	.009240	.006312	41.377	34.471	41.377	34.471	110.41

TRANSITIONAL CRACK GROWTH BETWEEN
THE END OF PART-THRU CRACK AND UNIFORM THRU CRACK

CRACK LENGTH (IN) B	C	C/B	TIME (PASSES)	GROWTH RATE (IN/PASS) @BACK	@FRONT	ALPHA-AXIAL @B	@C	K(MAX) B.	C.	TIME (HOURS)
.16109	.40225	2.4970	110.408	.009240	.006312	41.377	34.471	41.377	34.471	110.41
.21543	.45225	2.[illegible]	116.288	.067736	.007144	103.080	35.946	103.080	35.946	116.29
.48167	.48167	1.0000	120.219	.011263	.011263	44.489	44.489	44.489	44.489	120.22

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.4817	120.219	.011263	44.4889	44.4889	120.22
.5317	120.490	.271107	46.4913	46.4913	120.49
.6317	120.710	.718488	51.6459	51.6459	120.71
.7317	121.266	.000000	59.6441	59.6441	121.27

** K(MAX) REACHED KC WHICH HAS BEEN INPUT AS 60.900

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

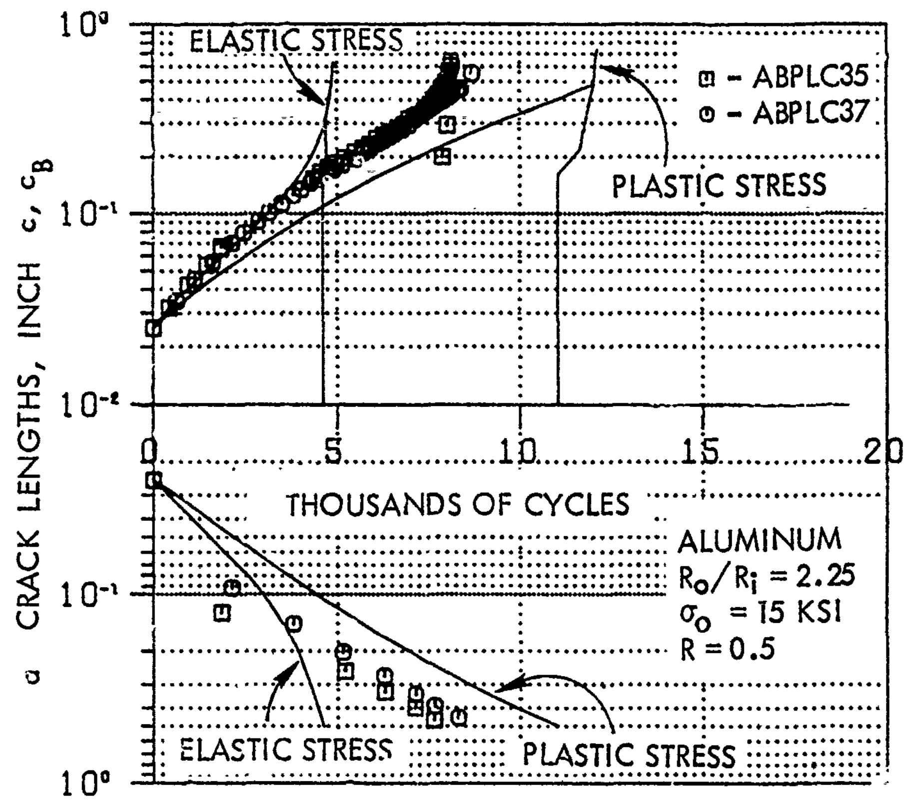


Figure 3-5. Corner Crack Growth Data and Prediction, Aluminum Lug, R_o/R_i=2.25, σ_o=15 KSI, R=0.5

SAMPLE PROBLEM #9

In all the sample problems presented thus far, only simple constant amplitude loading is illustrated. This sample shows the input for a slightly complex block spectrum loading. The schematic and details of block spectrum loading are given in Figure 3-6 and Table 3-1. The method of inputting the block spectrum is shown in the input data.

The above block spectrum will introduce spectrum retardation effects. The Generalized Willenborg model ('IRETAR' = 1 and 'IMODEL' = 2) is used in this sample problem to account for the crack growth retardation effect. Values of 0.0 and 3.5 are used in the input for the parameters 'XKMXTH' (maximum threshold stress intensity factor) and 'SOS' (overload shut off ratio), respectively. These values correspond to a value of 0.4 for the factor ϕ of the Generalized Willenborg equation. The plastic zone is calculated assuming a plane stress condition ('IPLANE' = 1).

Figure 3-7 shows the analytical-experimental data correlation for this sample problem. The labels mean the following.

[A] - Hsu retardation model is used

[B] - Generalized Willenborg model is used (Present output data)

[C] - Willenborg model is used

[D] - No retardation effect is considered.

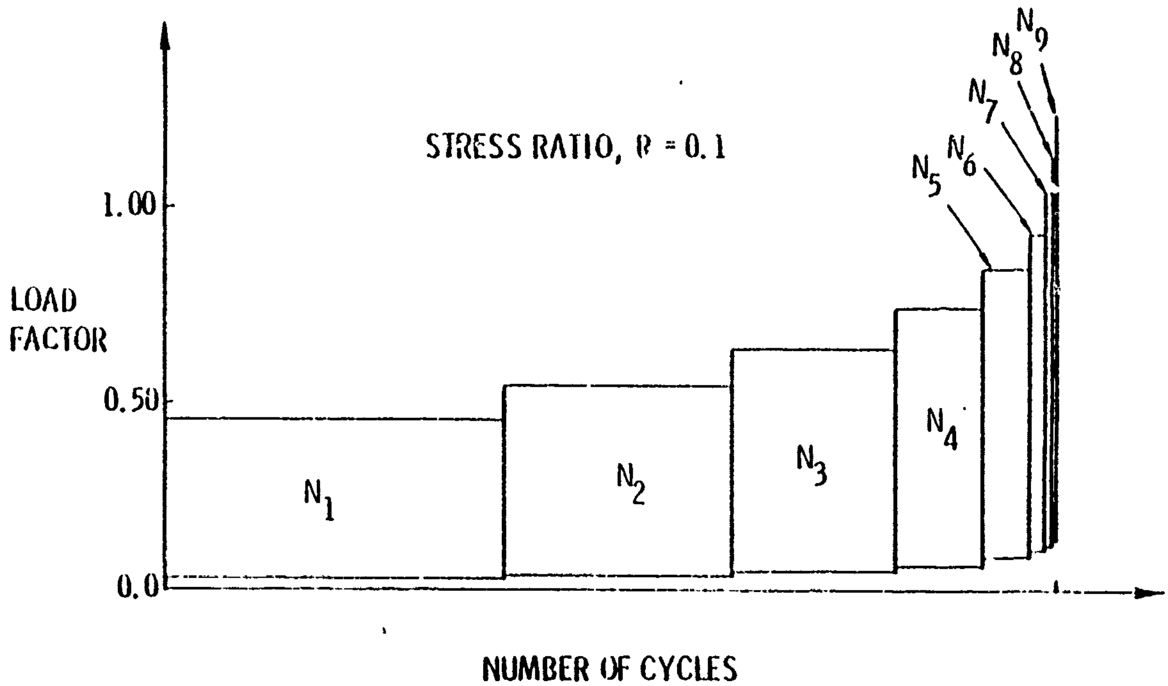


Figure 3-6. Schematic of Block Spectrum Loading.

TABLE 3.1. DETAILS OF BLOCK SPECTRUM LOADING

STRESS DATA			CYCLE DATA	
LOAD FACTOR		MAX. STRESS LEVEL (KSI)	SYMBOL	NO. OF CYCLES
SYMBOL	VALUE			
σ_1	0.45	2.7	N_1	950
σ_2	0.55	3.3	N_2	650
σ_3	0.65	3.9	N_3	450
σ_4	0.75	4.5	N_4	250
σ_5	0.85	5.1	N_5	136
σ_6	0.95	5.7	N_6	44
σ_7	1.05	6.3	N_7	15
σ_8	1.15	6.9	N_8	4
σ_9	1.25	7.5	N_9	1

NOTE: UNIT LOAD FACTOR = 6 KSI; R = 0.1

```
 1: ABPLS76
 2:    2     0     0     1
 3:   12     0
 4:          4.0       0.145
 5:          5.0       0.578
 6:          6.0       2.050
 7:          8.0       7.500
 8:         10.0      12.900
 9:         12.0      18.200
10:         15.0      28.300
11:         20.0      58.900
12:         25.0     134.000
13:         30.0     353.000
14:         40.0    2850.000
15:         45.0    6520.000
16:        60.94         0.1          -0.1
17:          0.0       60.94          74.9
18:    1     2
19:    1                       0.0          3.5
20:    1     1     9
21:BLOCK SPECTRUM DEFINITION
22:          1.0         1.0
23:          2.7         0.1         950.0
24:          3.3         0.1         650.0
25:          3.9         0.1         450.0
26:          4.5         0.1         250.0
27:          5.1         0.1         136.0
28:          5.7         0.1          44.0
29:          6.3         0.1          15.0
30:          6.9         0.1           4.0
31:          7.5         0.1           1.0
32:   0
33:   0      1
34:   1      1
35:   1      2      0
36:   0.7500     3.375      0.5000
37:   0.1136     0.9375
38:  11      0      0
39:   0.0000    5.3190
40:   0.0625    4.2290
41:   0.1875    3.0938
42:   0.3125    2.3490
43:   0.4375    1.9395
44:   0.5625    1.6268
45:   0.6875    1.3950
46:   0.8125    1.1700
47:   0.9375    0.9720
48:   1.0625    0.7200
49:   1.1875    0.4073
```

Line 7: IRETAR = 1, IMODEL = 2, Account retardation effect with Generalized Willenborg model

Line 8: IPLANE = 1, XKMXTH = 0.0, SOS = 3.5

Line 12: Block Spectrum Loading

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (ΔK) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.145		
		.15495-08	6.10807
5.000	.578		
		.48270-09	6.83274
6.000	2.050		
		.40294-07	4.36335
8.000	7.500		
		.33687-05	2.23485
10.000	12.900		
		.13326-04	1.63761
12.000	18.200		
		.12827-04	1.65297
15.000	28.300		
		.40159-05	2.08180
20.000	58.900		
		.26467-06	2.98961
25.000	134.000		
		.38102-08	4.30708
30.000	353.000		
		.72959-10	5.47007
40.000	2850.000		
		.90365-07	3.53948
45.000	6520.000		

KC VALUE USED IN FORMAN EQUATION IS 60.940 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .1000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000 .

* MISSION NO. 1 STRESS SPECTRUM FOR BLOCK SPECTRUM DEFINITION
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	S (SMAX-SMIN)	CYCLE/PASS
1	2.700	.270	.100	2.430	950.0
2	3.300	.330	.100	2.970	650.0
3	3.900	.390	.100	3.510	450.0
4	4.500	.450	.100	4.050	250.0
5	5.100	.510	.100	4.590	136.0
6	5.700	.570	.100	5.130	44.0
7	6.300	.630	.100	5.670	15.0
8	6.900	.690	.100	6.210	4.0
9	7.500	.750	.100	6.750	1.0

```
ABPLS76

        FORMAN S EQUATION IS USED IN ANALYSIS


       * THRU CRACK EMANATING FROM A LUG HOLE *
        GREEN FUNCTION APPROACH IS USED

        RADIUS OF THE HOLE IS    .7500 IN.
        WIDTH OF THE LUG IS     3.3750 IN.
        THICKNESS OF THE LUG IS      .5000 IN.
        RATIO OF W/D IS    2.2500

        INITIAL CRACK LENGTH IS    .1136 IN.
        GENERALIZED WILLENBORG RETARDATION MODEL IS USED IN THE CALCULATION
         TENSILE YIELD STRENGTH IS  74.900 KSI
         MAXIMUM THRESHOLD STRESS INTENSITY FACTOR IS     .000 KSI SQ.ROOT INCH
         AND OVERLOAD SHUT-OFF RATIO IS   3.500
        PLANE STRESS YIELD ZONE IS USED
        THRESHOLD ^K IS INPUT AS     .000 KSI*SQRT(IN)
        FRACTURE TOUGHNESS KC IS INPUT AS  60.940 KSI*SQRT(IN)
```

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	5.319	5.319
.063	4.239	4.239
.188	3.094	3.094
.313	2.349	2.349
.438	1.940	1.940
.563	1.627	1.627
.688	1.395	1.395
.813	1.170	1.170
.938	.972	.972
1.062	.720	.720
1.187	.407	.407

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0047	.0062	5.8242
.0094	.0125	5.7693
.0187	.0250	5.4661
.0469	.0625	4.5984
.0750	.1000	4.1814
.0937	.1250	3.9398
.1406	.1875	3.5187
.1875	.2500	3.1782
.2344	.3125	2.9701
.2813	.3750	2.8063
.3281	.4375	2.6753
.3750	.5000	2.5586
.4219	.5625	2.5003
.4688	.6250	2.4513
.5625	.7500	2.4172
.6563	.8750	2.4794
.7500	1.0000	2.6710
.7969	1.0625	2.9624
.8437	1.1250	3.3401
.8906	1.1875	3.7771

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.1136	.000	.000000	2.2231	16.6731	.00
.1336	5.019	.005561	2.3087	17.3151	5.02
.1536	8.442	.006041	2.3666	17.7492	8.44
.1736	11.665	.006369	2.4094	18.0707	11.67
.1936	14.722	.006716	2.4535	18.4010	14.72
.2136	17.620	.007087	2.5001	18.7509	17.62
.2636	24.256	.007981	2.6042	19.5318	24.26
.3136	30.215	.008802	2.6920	20.1897	30.21
.3636	35.679	.009500	2.7623	20.7176	35.68
.4136	40.668	.010542	2.8606	21.4542	40.67
.4636	45.156	.011740	2.9641	22.2308	45.16
.5136	49.178	.013125	3.0888	23.1661	49.18
.6136	55.796	.017094	3.4023	25.5170	55.80
.7136	60.572	.024784	3.8903	29.1771	60.57
.8136	63.095	.054497	4.9551	37.1633	63.09

FAILURE DUE TO NET SECTION YIELD (STRESS = 102.15 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 2500.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

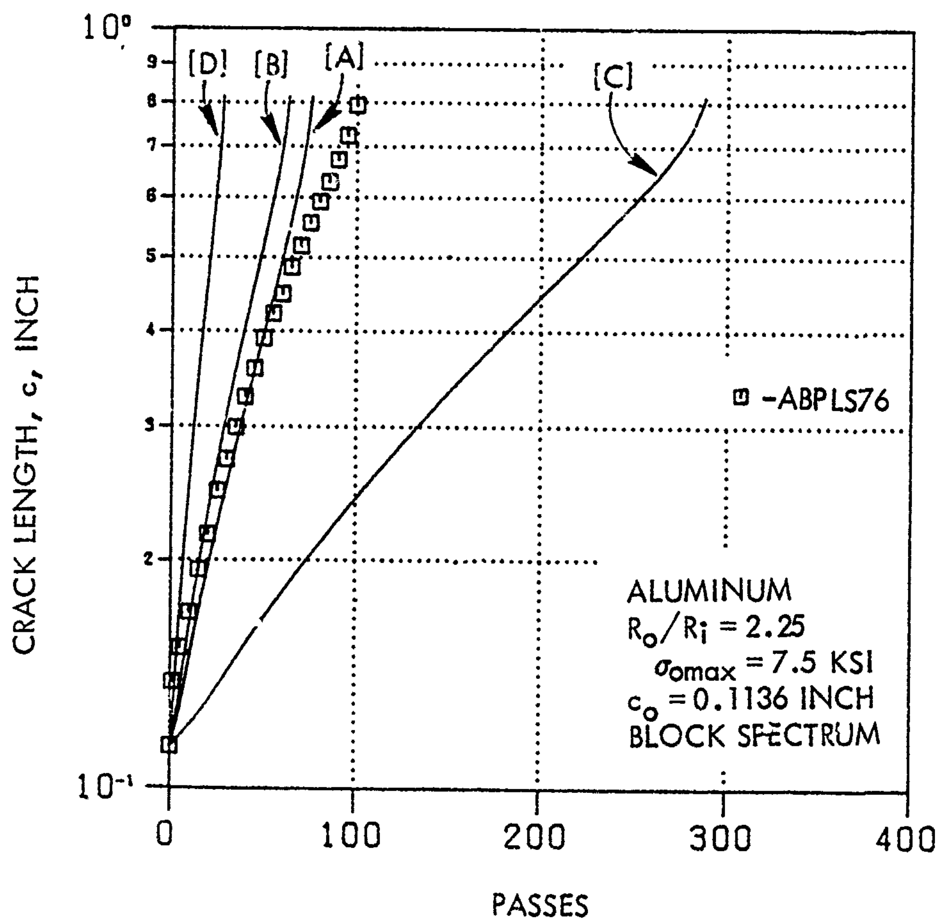


Figure 3-7. Through-the-Thickness Crack Growth Data and Prediction, Aluminum Lug, R_o/R_i=2.25, Block Spectrum Loading, σ_{omax} = 7.5 KSI

SAMPLE PROBLEM #10

This example corresponds to prediction of corner crack growth behavior in a lug subjected to a much more complex spectrum of flight-by-flight loading. This spectrum is typical for a cargo aircraft (C-5). This spectrum includes thirteen different missions (0, 1 through 12). The details of the missions are provided in Table 3-2. In this table, a special loading cycle is defined in terms of N/FLT = 0.1, for example in Mission 1. This simply means that the particular load is applied once in ten occurrences of this mission. When Mission 1 includes this load it is referred to as Mission 1*. In the input for this problem, Mission 1 and Mission 1* are treated as separate missions. The sequence of missions in one pass (mission mix) of the spectrum is given in Table 3-3. One pass consists of 120 missions and one mission has the same meaning as a flight.

In this sample problem, the Hsu retardation model ('IRETAR' = 1 and 'IMODEL' = 3) is used and the yield zone is calculated using the plane strain condition ('IPLANE' = 2).

Analytical and experimental results are compared in Figure 3-8. Labels [A], [B], [C] and [D] mean the same models as given in sample problem #9.

TABLE 3-2. MISSIONS DEFINITION FOR CARGO SPECTRUM

	MAX STRESS KSI	MIN STRESS KSI	N/FLT
MIS 0			
	19.108	-1.184	1.00
MIS 1			
	18.083	-1.808	1.00
	4.423	2.423	1998.00
	13.492	9.492	193.00
	15.106	9.106	24.00
	15.863	7.863	4.00
	16.909	5.572	1.00
	18.083	2.602	.10 *
MIS 2			
	17.987	-1.799	1.00
	5.080	3.080	2273.00
	13.824	9.824	204.00
	15.189	9.189	25.00
	15.908	7.908	5.00
	16.899	5.494	1.00
	17.987	2.384	.10
MIS 3			
	16.751	-1.675	1.00
	4.888	2.888	2891.00
	14.139	10.139	227.00
	15.304	9.304	25.00
	15.918	7.918	4.00
	16.751	5.302	1.00
MIS 4			
	16.695	-1.669	1.00
	6.157	4.157	2827.00
	14.755	10.755	209.00
	15.562	9.562	23.00
	16.065	8.065	4.00
	16.695	5.536	1.00
MIS 5			
	17.952	-1.795	1.00
	4.737	2.737	2099.00
	14.329	10.329	175.00
	15.420	9.420	21.00
	16.101	8.101	4.00
	16.936	5.964	1.00
	17.952	2.388	.10

* N/FLT = 0.1-Means the application of this load once in ten occurrences of this mission (refer to sequence of missions table).

TABLE 3-2. MISSIONS DEFINITION FOR CARGO SPECTRUM (CONTINUED)

	MAX STRESS KSI	MIN STRESS KSI	N/FLT
MIS 6			
	16.778	-1.678	1.00
	6.313	4.313	3082.00
	15.372	11.372	204.00
	15.904	9.904	21.00
	16.321	8.321	3.00
	16.778	6.050	1.00
MIS 7			
	17.861	-1.786	1.00
	5.628	3.628	2100.00
	14.634	10.634	164.00
	15.592	9.592	19.00
	16.232	8.232	3.00
	16.916	6.358	1.00
	17.861	3.335	.10
MIS 8			
	17.518	-1.752	1.00
	6.414	4.414	2714.00
	15.401	11.401	187.00
	15.941	9.941	19.00
	16.373	8.373	3.00
	16.820	6.253	1.00
	17.518	2.991	.10
MIS 9			
	17.761	-1.776	1.00
	6.544	4.544	2260.00
	15.197	11.197	161.00
	15.858	9.858	17.00
	16.406	8.406	2.00
	16.913	6.694	1.00
	17.761	3.686	.10
MIS 10			
	17.001	-1.700	1.00
	6.806	4.806	1989.00
	15.273	11.273	151.00
	15.918	9.918	18.00
	16.475	8.475	2.00
	17.001	6.760	1.00

TABLE 3-2. MISSIONS DEFINITION FOR CARGO SPECTRUM (CONTINUED)

	MAX STRESS KSI	MIN STRESS KSI	N/FLT
MIS 11			
	14.546	-1.808	1.00
	15.523	.000	1.00
	15.523	.000	1.00
	15.523	.000	1.00
	18.083	.000	1.00
	15.523	.000	1.00
	15.523	.000	1.00
	15.523	.000	1.00
	16.191	.000	1.00
	16.191	.000	1.00
	3.774	1.774	5418.00
	12.842	8.842	419.00
	14.546	8.546	51.00
	15.523	7.523	9.00
	16.191	6.191	2.00
	16.913	4.425	1.00
	18.083	1.151	.10
MIS 12			
	15.650	-1.849	1.00
	15.650	.000	1.00
	15.650	.000	1.00
	15.650	.000	1.00
	18.487	-1.849	1.00
	15.650	.000	1.00
	16.323	.000	1.00
	16.323	.000	1.00
	16.323	.000	1.00
	3.848	1.848	6512.00
	13.112	9.112	556.00
	14.771	8.771	69.00
	15.650	7.650	12.00
	16.323	6.323	5.00
	17.267	4.096	1.00
	18.487	.919	.10

TABLE 3-3. ONE PASS OF SEQUENCE OF MISSIONS OF CARGO SPECTRUM

SEQUENCE NO.	MISSION NO.	SEQUENCE NO.	MISSION NO.	SEQUENCE NO.	MISSION NO.
1	7	41	2	81	7
2	8	42	5	82	12
3	1	43	12	83	11
4	2	44	7	84	9
5	12*	45	2*	85	7
6	7	46	8	86	8*
7	5	47	1	87	2
8	11	48	9	88	5
9	8	49	4	89	1
10	9	50	7	90	12
11	7	51	12	91	7
12	1	52	8	92	10
13	12	53	11	93	8
14	2	54	5	94	11
15	7*	55	7*	95	3
16	8	56	1	96	7*
17	11	57	2	97	2
18	5	58	12	98	1
19	1	59	8	99	12
20	7	60	7	100	5
21	12	61	0	101	7
22	4	62	3	102	8
23	2	63	5	103	9
24	7	64	1	104	2
25	8*	65	7	105	7
26	6	66	12*	106	11*
27	11	67	8	107	12
28	1	68	2	108	1
29	12	69	11	109	8
30	7	70	9	110	5
31	8	71	7	111	7
32	2	72	1	112	2
33	5	73	12	113	12
34	7	74	8	114	8
35	1*	75	7	115	7
36	9	76	5*	116	9*
37	12	77	2	117	1
38	8	78	4	118	11
39	11	79	1	119	4
40	7	80	8	120	12

*Missions with application of once in ten occurrances loads (i.e., loads with N/FLT = 0.1)

```
 1: SBPLS56 AND SBPLS54
 2:    2      0      0      0
 3:   13      0
 4:        4.0     0.0537
 5:        5.0     0.106
 6:        7.0     0.247
 7:        9.0     0.482
 8:       11.0     0.833
 9:       13.0     1.310
10:       16.0     2.250
11:       20.0     3.930
12:       24.0     6.010
13:       28.0     8.350
14:       35.0    12.800
15:       50.0    29.000
16:       58.0    57.700
17:      224.7       0.5        -0.1
18:        0.0     224.7       179.7
19:    1      3
20:    2
21:    1      2      1
22: MISSION 0
23:        1.0         1.0
24:     19.108      -1.184         1.0
25:    2      2      6
26: MISSION 1
27:        1.0         1.0
28:     18.083      -1.808         1.0
29:      4.423       2.423      1998.0
30:     13.492       9.492       193.0
31:     15.106       9.106        24.0
32:     15.863       7.863         4.0
33:     16.909       5.572         1.0
34:    3      2      7
35: MISSION 1*
36:        1.0         1.0
37:     18.083      -1.808         1.0
38:      4.423       2.423      1998.0
39:     13.492       9.492       193.0
40:     15.106       9.106        24.0
41:     15.863       7.863         4.0
42:     16.909       5.572         1.0
43:     18.083       2.602         1.0
44:    4      2      6
45: MISSION 2
46:        1.0         1.0
47:     17.987      -1.799         1.0
48:      5.080       3.080      2273.0
49:     13.824       9.824       204.0
50:     15.189       9.189        25.0
```

Line 7: IRETAR = 1, IMODEL = 3,
Account retardation
effect with Hsu model

Line 8: IPLANE = 2

Lines 9,10,11, 12*, 13:
Flight-by-flight
cargo spectrum
definition beginning

```
      15.908      7.908        5.0
      16.899      5.494        1.0
      5    2      7
 MISSION 2*
         1.0        1.0
      17.987     -1.799        1.0
       5.080      3.080     2273.0
      13.824      9.824      204.0
      15.189      9.189       25.0
      15.908      7.908        5.0
      16.899      5.494        1.0
      17.987      2.384        1.0
      6    2      6
 MISSION 3
         1.0        1.0
      16.751     -1.675        1.0
       4.888      2.888     2891.0
      14.139     10.139      227.0
      15.304      9.304       25.0
      15.918      7.918        4.0
      16.751      5.302        1.0
      7    2      6
 MISSION 4
         1.0        1.0
      16.695     -1.669        1.0
       6.157      4.157     2827.0
      14.755     10.755      209.0
      15.562      9.562       23.0
      16.065      8.065        4.0
      16.695      5.536        1.0
      8    2      6
 MISSION 5
         1.0        1.0
      17.952     -1.795        1.0
       4.737      2.737     2099.0
      14.329     10.329      175.0
      15.420      9.420       21.0
      16.101      8.101        4.0
      16.936      5.964        1.0
      9    2      7
 MISSION 5*
         1.0        1.0
      17.952     -1.795        1.0
       4.737      2.737     2099.0
      14.329     10.329      175.0
      15.420      9.420       21.0
      16.101      8.101        4.0
      16.936      5.964        1.0
      17.952      2.888        1.0
     10    2      6
```

```
MISSION 6
        1.0        1.0
     16.778     -1.678        1.0
      6.313      4.313     3082.0
     15.372     11.372      204.0
     15.904      9.904       21.0
     16.321      8.321        3.0
     16.778      6.050        1.0
   11      2      6
MISSION 7
        1.0        1.0
     17.861     -1.786        1.0
      5.628      3.628     2100.0
     14.634     10.634      164.0
     15.592      9.592       19.0
     16.232      8.232        3.0
     16.916      6.358        1.0
   12      2      7
MISSION 7*
        1.0        1.0
     17.861     -1.786        1.0
      5.628      3.628     2100.0
     14.634     10.634      164.0
     15.592      9.592       19.0
     16.232      8.232        3.0
     16.916      6.358        1.0
     17.861      3.335        1.0
   13      2      6
MISSION 8
        1.0        1.0
     17.518     -1.752        1.0
      6.414      4.414     2714.0
     15.401     11.401      187.0
     15.941      9.941       19.0
     16.373      8.373        3.0
     16.820      6.253        1.0
   14      2      7
MISSION 8*
        1.0        1.0
     17.518     -1.752        1.0
      6.414      4.414     2714.0
     15.401     11.401      187.0
     15.941      9.941       19.0
     16.373      8.373        3.0
     16.820      6.253        1.0
     17.518      2.991        1.0
   15      2      6
MISSION 9
        1.0        1.0
     17.761     -1.776        1.0
```

151:	6.544	4.544	2260.0
152:	15.197	11.197	161.0
153:	15.858	9.858	17.0
154:	16.406	8.406	2.0
155:	16.913	6.694	1.0
156:	16 2	7	
157:	MISSION 9*		
158:	1.0	1.0	
159:	17.761	-1.776	1.0
160:	6.544	4.544	2260.0
161:	15.197	11.197	161.0
162:	15.858	9.858	17.0
163:	16.406	8.406	2.0
164:	16.913	6.694	1.0
165:	17.761	3.686	1.0
166:	17 2	6	
167:	MISSION 10		
168:	1.0	1.0	
169:	17.001	-1.700	1.0
170:	6.806	4.806	1989.0
171:	15.273	11.273	151.0
172:	15.918	9.918	18.0
173:	16.475	8.475	2.0
174:	17.001	6.760	1.0
175:	18 2	11	
176:	MISSION 11		
177:	1.0	1.0	
178:	14.546	-1.808	1.0
179:	15.523	0.000	3.0
180:	18.083	0.000	1.0
181:	15.523	0.000	3.0
182:	16.191	0.000	2.0
183:	3.774	1.774	5418.0
184:	12.842	8.842	419.0
185:	14.546	8.546	51.0
186:	15.523	7.523	9.0
187:	16.191	6.191	2.0
188:	16.913	4.425	1.0
189:	19 2	12	
190:	MISSION 11*		
191:	1.0	1.0	
192:	14.546	-1.808	1.0
193:	15.523	0.000	3.0
194:	18.083	0.000	1.0
195:	15.523	0.000	3.0
196:	16.191	0.000	2.0
197:	3.774	1.774	5418.0
198:	12.842	8.842	419.0
199:	14.546	8.546	51.0
200:	15.523	7.523	9.0

```
201:     16.191      6.191        2.0
202:     16.913      4.425        1.0
203:     18.083      1.151        1.0
204:   20     2    11
205: MISSION 12
206:        1.0        1.0
207:     15.650     -1.849        1.0
208:     15.650      0.000        3.0
209:     18.487     -1.849        1.0
210:     15.650      0.000        1.0
211:     16.323      0.000        3.0
212:      3.848      1.848     6512.0
213:     13.112      9.112      556.0
214:     14.771      8.771       69.0
215:     15.650      7.650       12.0
216:     16.323      6.323        5.0
217:     17.267      4.096        1.0
218:   21     2    12
219: MISSION 12*
220:        1.0        1.0
221:     15.650     -1.849        1.0
222:     15.650      0.000        3.0
223:     18.487     -1.849        1.0
224:     15.650      0.000        1.0
225:     16.323      0.000        3.0
226:      3.848      1.848     6512.0
227:     13.112      9.112      556.0
228:     14.771      8.771       69.0
229:     15.650      7.650       12.0
230:     16.323      6.323        5.0
231:     17.267      4.096        1.0
232:     18.487      0.919        1.0
233:     0
234:     0   120
235:     1    11
236:     1    13
237:     1     2
238:     1     4
239:     1    21
240:     1    11
241:     1     8
242:     1    18
243:     1    13
244:     1    15
245:     1    11
246:     1     2
247:     1    20
248:     1     4
249:     1    12
250:     1    13
```

Flight-by-flight cargo spectrum definition ending

Lines 14,15:

Mission mix definition beginning

251:	1	18
252:	1	8
253:	1	2
254:	1	11
255:	1	20
256:	1	7
257:	1	4
258:	1	11
259:	1	14
260:	1	10
261:	1	18
262:	1	2
263:	1	20
264:	1	11
265:	1	13
266:	1	4
267:	1	8
268:	1	11
269:	1	3
270:	1	15
271:	1	20
272:	1	13
273:	1	18
274:	1	11
275:	1	4
276:	1	8
277:	1	20
278:	1	11
279:	1	5
280:	1	13
281:	1	2
282:	1	15
283:	1	7
284:	1	11
285:	1	20
286:	1	13
287:	1	18
288:	1	8
289:	1	12
290:	1	2
291:	1	4
292:	1	20
293:	1	13
294:	1	11
295:	1	1
296:	1	6
297:	1	8
298:	1	2
299:	1	11
300:	1	21

301:	1	13
302:	1	4
303:	1	18
304:	1	15
305:	1	11
306:	1	2
307:	1	20
308:	1	13
309:	1	11
310:	1	9
311:	1	4
312:	1	7
313:	1	2
314:	1	13
315:	1	11
316:	1	20
317:	1	18
318:	1	15
319:	1	11
320:	1	14
321:	1	4
322:	1	8
323:	1	2
324:	1	20
325:	1	11
326:	1	17
327:	1	13
328:	1	18
329:	1	6
330:	1	12
331:	1	4
332:	1	2
333:	1	20
334:	1	8
335:	1	11
336:	1	13
337:	1	15
338:	1	4
339:	1	11
340:	1	19
341:	1	20
342:	1	2
343:	1	13
344:	1	8
345:	1	11
346:	1	4
347:	1	20
348:	1	13
349:	1	11
350:	1	16

```
  1       2
  1      18
  1       7
  1      20
  0       2        0
  0.7500        4.500       0.5000
0.02500        1.5000
        0.5
11       0        0
        0.0        5.145
        0.1        4.101
        0.3        2.634
        0.5        1.854
        0.7        1.497
        0.9        1.248
        1.1        1.065
        1.3        0.897
        1.5        0.744
        1.7        0.558
        1.9        0.333
```

Mission mix
definition ending

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.054		
		.90169-07	3.00593
5.000	.106		
		.21769-06	2.45828
7.000	.247		
		.17046-06	2.58397
9.000	.482		
		.15443-06	2.62892
11.000	.833		
		.16918-06	2.59088
13.000	1.310		
		.23828-06	2.45734
16.000	2.250		
		.35921-06	2.30931
20.000	3.930		
		.69916-06	2.08700
24.000	6.010		
		.15690-05	1.83266
28.000	8.350		
		.43571-05	1.52614
35.000	12.800		
		.24456-05	1.68858
50.000	29.000		
		.89952-09	3.71003
58.000	57.700		

KC VALUE USED IN FORMAN EQUATION IS 224.700 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .5000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR MISSION 0
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	19.108	-1.184	-.062	20.292	1.0

* MISSION NO. 2 STRESS SPECTRUM FOR MISSION 1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	18.083	-1.808	-.100	19.891	1.0
2	4.423	2.423	.548	2.000	1998.0
3	13.492	9.492	.704	4.000	193.0
4	15.106	9.106	.603	6.000	24.0
5	15.863	7.863	.496	8.000	4.0
6	16.909	5.572	.330	11.337	1.0

* MISSION NO. 3 STRESS SPECTRUM FOR MISSION 1*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	18.083	-1.808	-.100	19.891	1.0
2	4.423	2.423	.548	2.000	1998.0
3	13.492	9.492	.704	4.000	193.0
4	15.106	9.106	.603	6.000	24.0
5	15.863	7.863	.496	8.000	4.0
6	16.909	5.572	.330	11.337	1.0
7	18.083	2.602	.144	15.481	1.0

* MISSION NO. 4 STRESS SPECTRUM FOR MISSION 2
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.987	-1.799	-.100	19.786	1.0
2	5.080	3.080	.606	2.000	2273.0
3	13.824	9.824	.711	4.000	204.0
4	15.189	9.189	.605	6.000	25.0
5	15.908	7.908	.497	8.000	5.0
6	16.899	5.494	.325	11.405	1.0

* MISSION NO. 5 STRESS SPECTRUM FOR MISSION 2*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.987	-1.799	-.100	19.786	1.0
2	5.080	3.080	.606	2.000	2273.0
3	13.824	9.824	.711	4.000	204.0
4	15.189	9.189	.605	6.000	25.0
5	15.908	7.908	.497	9.000	5.0
6	16.899	5.494	.325	11.405	1.0
7	17.987	2.384	.133	15.603	1.0

* MISSION NO. 6 STRESS SPECTRUM FOR MISSION 3
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	16.751	-1.675	-.100	18.426	1.0
2	4.888	2.888	.591	2.000	2891.0
3	14.139	10.139	.717	4.000	227.0
4	15.304	9.304	.608	6.000	25.0
5	15.918	7.918	.497	8.000	4.0
6	16.751	5.302	.317	11.449	1.0

* MISSION NO. 7 STRESS SPECTRUM FOR MISSION 4
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	16.695	-1.669	-.100	18.364	1.0
2	6.157	4.157	.675	2.000	2827.0
3	14.755	10.755	.729	4.000	209.0
4	15.562	9.562	.614	6.000	23.0
5	16.065	8.065	.502	8.000	4.0
6	16.695	5.536	.332	11.159	1.0

* MISSION NO. 8 STRESS SPECTRUM FOR MISSION 5
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.952	-1.795	-.100	19.747	1.0
2	4.737	2.737	.578	2.000	2099.0
3	14.329	10.329	.721	4.000	175.0
4	15.420	9.420	.611	6.000	21.0
5	16.101	8.101	.503	8.000	4.0
6	16.936	5.964	.352	10.972	1.0

* MISSION NO. 9 STRESS SPECTRUM FOR MISSION 5*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.952	-1.795	-.100	19.747	1.0
2	4.737	2.737	.578	2.000	2099.0
3	14.329	10.329	.721	4.000	175.0
4	15.420	9.420	.611	6.000	21.0
5	16.101	8.101	.503	8.000	4.0
6	16.936	5.964	.352	10.972	1.0
7	17.952	2.888	.161	15.064	1.0

* MISSION NO. 10 STRESS SPECTRUM FOR MISSION 6
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	16.778	-1.678	-.100	18.456	1.0
2	6.313	4.313	.683	2.000	3082.0
3	15.372	11.372	.740	4.000	204.0

4	15.904	9.904	.623	6.000	21.0
5	16.321	8.321	.510	8.000	3.0
6	16.778	6.050	.361	10.728	1.0

* MISSION NO. 11 STRESS SPECTRUM FOR MISSION 7
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.861	-1.786	-.100	19.647	1.0
2	5.628	3.628	.645	2.000	2100.0
3	14.634	10.634	.727	4.000	164.0
4	15.592	9.592	.615	6.000	19.0
5	16.232	8.232	.507	8.000	3.0
6	16.916	6.358	.376	10.558	1.0

* MISSION NO. 12 STRESS SPECTRUM FOR MISSION 7*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.861	-1.786	-.100	19.647	1.0
2	5.628	3.628	.645	2.000	2100.0
3	14.634	10.634	.727	4.000	164.0
4	15.592	9.592	.615	6.000	19.0
5	16.232	8.232	.507	8.000	3.0
6	16.916	6.358	.376	10.558	1.0
7	17.861	3.335	.187	14.526	1.0

* MISSION NO. 13 STRESS SPECTRUM FOR MISSION 8
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.518	-1.752	-.100	19.270	1.0
2	6.414	4.414	.688	2.000	2714.0
3	15.401	11.401	.740	4.000	187.0
4	15.941	9.941	.624	6.000	19.0
5	16.373	8.373	.511	8.000	3.0
6	16.820	6.253	.372	10.567	1.0

* MISSION NO. 14 STRESS SPECTRUM FOR MISSION 8*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.518	-1.752	-.100	19.270	1.0
2	6.414	4.414	.688	2.000	2714.0
3	15.401	11.401	.740	4.000	187.0
4	15.941	9.941	.624	6.000	19.0
5	16.373	8.373	.511	8.000	3.0
6	16.820	6.253	.372	10.567	1.0
7	17.518	2.991	.171	14.527	1.0

* MISSION NO. 15 STRESS SPECTRUM FOR MISSION 9
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS

1	17.761	-1.776	-.100	19.537	1.0
2	6.544	4.544	.694	2.000	2260.0
3	15.197	11.197	.737	4.000	161.0
4	15.858	9.858	.622	6.000	17.0
5	16.406	8.406	.512	8.000	2.0
6	16.913	6.694	.396	10.219	1.0

* MISSION NO. 16 STRESS SPECTRUM FOR MISSION 9*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.761	-1.776	-.100	19.537	1.0
2	6.544	4.544	.694	2.000	2260.0
3	15.197	11.197	.737	4.000	161.0
4	15.858	9.858	.622	6.000	17.0
5	16.406	8.406	.512	8.000	2.0
6	16.913	6.694	.396	10.219	1.0
7	17.761	3.686	.208	14.075	1.0

* MISSION NO. 17 STRESS SPECTRUM FOR MISSION 10
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	17.001	-1.700	-.100	18.701	1.0
2	6.806	4.806	.706	2.000	1989.0
3	15.273	11.273	.738	4.000	151.0
4	15.918	9.918	.623	6.000	18.0
5	16.475	8.475	.514	8.000	2.0
6	17.001	6.760	.398	10.241	1.0

* MISSION NO. 18 STRESS SPECTRUM FOR MISSION 11
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	14.546	-1.808	-.124	16.354	1.0
2	15.523	.000	.000	15.523	3.0
3	18.083	.000	.000	18.083	1.0
4	15.523	.000	.000	15.523	3.0
5	16.191	.000	.000	16.191	2.0
6	3.774	1.774	.470	2.000	5418.0
7	12.842	8.842	.689	4.000	419.0
8	14.546	8.546	.588	6.000	51.0
9	15.523	7.523	.485	8.000	9.0
10	16.191	6.191	.382	10.000	2.0
11	16.913	4.425	.262	12.488	1.0

* MISSION NO. 19 STRESS SPECTRUM FOR MISSION 11*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	14.546	-1.808	-.124	16.354	1.0
2	15.523	.000	.000	15.523	3.0
3	18.083	.000	.000	18.083	1.0
4	15.523	.000	.000	15.523	3.0

5	16.191	.000	.000	16.191	2.0
6	3.774	1.774	.470	2.000	5418.0
7	12.842	8.842	.689	4.000	419.0
8	14.546	8.546	.588	6.000	51.0
9	15.523	7.523	.485	8.000	9.0
10	16.191	6.191	.382	10.000	2.0
11	16.913	4.425	.262	12.488	1.0
12	18.083	1.151	.064	16.932	1.0

* MISSION NO. 20 STRESS SPECTRUM FOR MISSION 12
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	15.650	-1.849	-.118	17.499	1.0
2	15.650	.000	.000	15.650	3.0
3	18.487	-1.849	-.100	20.336	1.0
4	15.650	.000	.000	15.650	1.0
5	16.323	.000	.000	16.323	3.0
6	3.848	1.848	.480	2.000	6512.0
7	13.112	9.112	.695	4.000	556.0
8	14.771	8.771	.594	6.000	69.0
9	15.650	7.650	.489	8.000	12.0
10	16.323	6.323	.387	10.000	5.0
11	17.267	4.096	.237	13.171	1.0

* MISSION NO. 21 STRESS SPECTRUM FOR MISSION 12*
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	15.650	-1.849	-.118	17.499	1.0
2	15.650	.000	.000	15.650	3.0
3	18.487	-1.849	-.100	20.336	1.0
4	15.650	.000	.000	15.650	1.0
5	16.323	.000	.000	16.323	3.0
6	3.848	1.848	.480	2.000	6512.0
7	13.112	9.112	.695	4.000	556.0
8	14.771	8.771	.594	6.000	69.0
9	15.650	7.650	.489	8.000	12.0
10	16.323	6.323	.387	10.000	5.0
11	17.267	4.096	.237	13.171	1.0
12	18.487	.719	.050	17.568	1.0

LOAD SPECTRUM

ONE PASS (MISSION MIX) CONTAINS120 SEGMENTS
APPLIED IN THE FOLLOWING SEQUENCES

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SEGMENT NO.  1 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  2 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  3 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  4 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.  5 CONTAINS  1 FLIGHT(S) OF MISSION NO. 21
SEGMENT NO.  6 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  7 CONTAINS  1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO.  8 CONTAINS  1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO.  9 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 10 CONTAINS  1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO. 11 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 12 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO. 13 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 14 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO. 15 CONTAINS  1 FLIGHT(S) OF MISSION NO. 12
SEGMENT NO. 16 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 17 CONTAINS  1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO. 18 CONTAINS  1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO. 19 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO. 20 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 21 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 22 CONTAINS  1 FLIGHT(S) OF MISSION NO.  7
SEGMENT NO. 23 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO. 24 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 25 CONTAINS  1 FLIGHT(S) OF MISSION NO. 14
SEGMENT NO. 26 CONTAINS  1 FLIGHT(S) OF MISSION NO. 10
SEGMENT NO. 27 CONTAINS  1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO. 28 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO. 29 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 30 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 31 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 32 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO. 33 CONTAINS  1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO. 34 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 35 CONTAINS  1 FLIGHT(S) OF MISSION NO.  3
SEGMENT NO. 36 CONTAINS  1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO. 37 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 38 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 39 CONTAINS  1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO. 40 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 41 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO. 42 CONTAINS  1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO. 43 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 44 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 45 CONTAINS  1 FLIGHT(S) OF MISSION NO.  5
SEGMENT NO. 46 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 47 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO. 48 CONTAINS  1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO. 49 CONTAINS  1 FLIGHT(S) OF MISSION NO.  7
SEGMENT NO. 50 CONTAINS  1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO. 51 CONTAINS  1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO. 52 CONTAINS  1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO. 53 CONTAINS  1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO. 54 CONTAINS  1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO. 55 CONTAINS  1 FLIGHT(S) OF MISSION NO. 12
SEGMENT NO. 56 CONTAINS  1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO. 57 CONTAINS  1 FLIGHT(S) OF MISSION NO.  4
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SEGMENT NO.  58 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.  59 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  60 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  61 CONTAINS   1 FLIGHT(S) OF MISSION NO.  1
SEGMENT NO.  62 CONTAINS   1 FLIGHT(S) OF MISSION NO.  6
SEGMENT NO.  63 CONTAINS   1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO.  64 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  65 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  66 CONTAINS   1 FLIGHT(S) OF MISSION NO. 21
SEGMENT NO.  67 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  68 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.  69 CONTAINS   1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO.  70 CONTAINS   1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO.  71 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  72 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  73 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.  74 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  75 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  76 CONTAINS   1 FLIGHT(S) OF MISSION NO.  9
SEGMENT NO.  77 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.  78 CONTAINS   1 FLIGHT(S) OF MISSION NO.  7
SEGMENT NO.  79 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  80 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  81 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  82 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.  83 CONTAINS   1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO.  84 CONTAINS   1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO.  85 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  86 CONTAINS   1 FLIGHT(S) OF MISSION NO. 14
SEGMENT NO.  87 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.  88 CONTAINS   1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO.  89 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  90 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.  91 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.  92 CONTAINS   1 FLIGHT(S) OF MISSION NO. 17
SEGMENT NO.  93 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.  94 CONTAINS   1 FLIGHT(S) OF MISSION NO. 18
SEGMENT NO.  95 CONTAINS   1 FLIGHT(S) OF MISSION NO.  6
SEGMENT NO.  96 CONTAINS   1 FLIGHT(S) OF MISSION NO. 12
SEGMENT NO.  97 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.  98 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.  99 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.100 CONTAINS   1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO.101 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.102 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.103 CONTAINS   1 FLIGHT(S) OF MISSION NO. 15
SEGMENT NO.104 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.105 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.106 CONTAINS   1 FLIGHT(S) OF MISSION NO. 19
SEGMENT NO.107 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.108 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.109 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.110 CONTAINS   1 FLIGHT(S) OF MISSION NO.  8
SEGMENT NO.111 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.112 CONTAINS   1 FLIGHT(S) OF MISSION NO.  4
SEGMENT NO.113 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
SEGMENT NO.114 CONTAINS   1 FLIGHT(S) OF MISSION NO. 13
SEGMENT NO.115 CONTAINS   1 FLIGHT(S) OF MISSION NO. 11
SEGMENT NO.116 CONTAINS   1 FLIGHT(S) OF MISSION NO. 16
SEGMENT NO.117 CONTAINS   1 FLIGHT(S) OF MISSION NO.  2
SEGMENT NO.118 CONTAINS   1 FLIGHT(S) OF MISSION NO. 10
SEGMENT NO.119 CONTAINS   1 FLIGHT(S) OF MISSION NO.  7
SEGMENT NO.120 CONTAINS   1 FLIGHT(S) OF MISSION NO. 20
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NOTE : ONE PASS =      120.0 HOURS
             OR =   406221.0 CYCLES
             OR =        857 LOAD LAYERS
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SBPLS56 AND SBPLS54

FORMAN S EQUATION IS USED IN ANALYSIS

* CORNER CRACK AT THE EDGE OF A LUG HOLE *
GREEN FUNCTION APPROACH IS USED

RADIUS OF THE HOLE IS .7500 IN.
WIDTH OF THE LUG IS 4.5000 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 3.0000

INITIAL CRACK LENGTH IS .0250 IN.
INITIAL FLAW SHAPE A/2C IS .5000
HSU'S RETARDATION MODEL IS USED IN THE CALCULATION
AND THE TENSILE YIELD STRENGTH IS 179.700 KSI
PLANE STRAIN YIELD ZONE IS USED
THRESHOLD ^K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 224.700 KSI*SQRT(IN)

UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	STRESS/UNIT LOAD	MAX. EFF. STRESS
.000	5.145	5.145
.100	4.101	4.101
.300	2.634	2.634
.500	1.854	1.854
.700	1.497	1.497
.900	1.248	1.248
1.100	1.065	1.065
1.300	.897	.897
1.500	.744	.744
1.700	.558	.558
1.900	.333	.333

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF MODIFIED GREEN'S FUNCTIONS

C	C/RI	BETA
.0075	.0100	5.6337
.0150	.0200	5.5807
.0300	.0400	5.2489
.0750	.1000	4.3033
.1200	.1600	3.8357
.1500	.2000	3.5511
.2250	.3000	3.0610
.3000	.4000	2.6824
.3750	.5000	2.4493
.4500	.6000	2.2703
.5250	.7000	2.1358
.6000	.8000	2.0184
.6750	.9000	1.9506
.7500	1.0000	1.8959
.9000	1.2000	1.8450
1.0500	1.4000	1.8683
1.2000	1.6000	1.9830
1.2750	1.7000	2.1816
1.3500	1.8000	2.4501
1.4250	1.9000	2.7789

PREDICTED PART-THROUGH CORNER CRACK GROWTH HISTORY
GROWTH RATE ALONG THE CRACK PERIPHERY IS VARIABLE

CRACK LENGTH (IN) A	C	AVERAGE A/2C	TIME (PASSES)	GROWTH RATE (IN/PASS) @HOLE	@SURFACE	ALPHA-AXIAL @A	@C	K(MAX) @A	@C	TIME (HOURS)
.02500	.02500	.5000	.000	.004255	.007014	.979	1.162	18.703	22.200	.00
.03000	.03317	.4522	1.045	.004784	.007816	1.113	1.219	21.267	23.294	125.41
.03500	.03959	.4420	1.778	.006824	.008770	1.201	1.279	22.949	24.435	213.34
.04000	.04544	.4402	2.368	.008474	.009898	1.278	1.333	24.427	25.474	284.15
.04500	.05092	.4419	2.866	.010028	.011002	1.344	1.382	25.689	26.400	343.98
.05000	.05617	.4451	3.303	.011462	.012041	1.403	1.424	26.801	27.216	396.32
.06000	.06606	.4542	4.045	.013469	.013312	1.499	1.495	28.651	28.563	485.42
.07000	.07549	.4636	4.677	.015922	.014933	1.582	1.548	30.221	29.581	561.26
.08000	.08466	.4725	5.228	.018158	.016642	1.665	1.621	31.808	30.976	627.35
.09000	.09370	.4803	5.714	.020574	.018599	1.741	1.684	33.261	32.169	685.67
.10000	.10257	.4875	6.149	.022978	.020282	1.810	1.737	34.589	33.195	737.90
.12000	.11945	.5023	6.899	.026686	.022520	1.930	1.823	36.881	34.829	827.82
.14000	.13594	.5149	7.552	.030606	.025234	2.040	1.879	38.983	35.908	906.25
.16000	.15176	.5272	8.135	.034310	.027141	2.137	1.921	40.843	36.713	976.20
.18000	.16682	.5395	8.658	.038223	.028786	2.228	1.973	42.571	37.693	1038.98
.20000	.18110	.5522	9.130	.042430	.030292	2.309	2.014	44.113	38.489	1095.54
.25000	.21287	.5872	10.129	.050035	.031798	2.464	2.084	47.080	39.829	1215.46
.30000	.24241	.6188	10.997	.057617	.034034	2.592	2.138	49.531	40.853	1319.60
.35000	.27013	.6478	11.771	.064553	.035792	2.694	2.176	51.485	41.582	1412.54
.40000	.29661	.6743	12.480	.070520	.037355	2.782	2.195	53.168	41.939	1497.62
.45000	.32216	.6984	13.138	.075981	.038813	2.861	2.235	54.672	42.704	1576.59
.50000	.34716	.7201	13.755	.081133	.040581	2.977	2.255	56.894	43.097	1650.54

TRANSITIONAL CRACK GROWTH BETWEEN
THE END OF PART-THRU CRACK AND UNIFORM THRU CRACK

CRACK LENGTH (IN) B	C	C/B	TIME (PASSES)	GROWTH RATE (IN/PASS) @BACK	@FRONT	ALPHA-AXIAL @B	@C	K(MAX) B,	C,	TIME (HOURS)
.15633	.34716	2.2201	13.755	.081133	.040581	2.977	2.255	56.894	43.097	1650.54
.23392	.39716	1.6978	14.710	.517871	.044874	5.884	2.329	112.426	44.509	1745.24
.41288	.41288	1.0000	15.056	.064587	.064587	2.679	2.679	51.193	51.193	1806.71

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.4129	15.056	.064587	2.6791	51.1930	1806.71
.4629	15.821	.066280	2.7069	51.7235	1898.49
.5129	16.564	.068300	2.7359	52.2785	1987.66
.6129	17.995	.071403	2.7831	53.1792	2159.45
.7129	19.343	.076971	2.8757	54.9492	2321.20
.8129	20.572	.085850	2.9907	57.1463	2468.64
.9129	21.665	.097041	3.1273	59.7560	2599.83
1.0129	22.624	.111495	3.3212	63.4616	2714.92
1.1129	23.446	.131796	3.5847	68.4973	2813.56
1.2129	24.123	.163721	3.9387	75.2616	2894.78
1.3129	24.591	.264148	4.7093	89.9859	2950.87

FAILURE DUE TO NET SECTION YIELD (STRESS = 229.76 KSI)

```
NOTE : ONE PASS IS EQUIVALENT TO     406221.0000 CYCLES
       ONE PASS IS EQUIVALENT TO  120.0000 FLIGHT HOURS
```

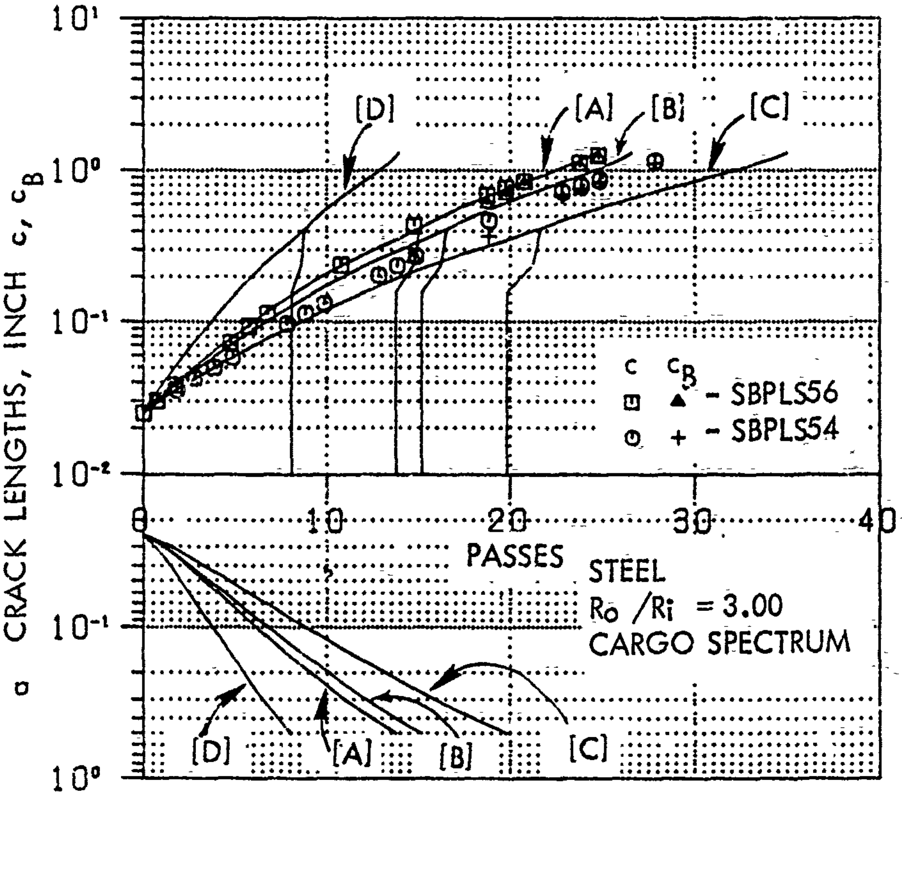

Figure 3-8. Corner Crack Growth Data and Prediction, Steel Lug, R_o/R_i=3.0, Cargo Spectrum Loading

SAMPLE PROBLEM #11

Analysis of a lug with an interference-fit bushing is illustrated in this sample problem. Details of the material and geometric parameters are:

Lug Material	:	Steel
Bushing Material	:	Steel
Lug Outer Radius, R_o	:	1.6875 Inch
Lug Inner Radius, R_i	:	0.84 Inch
Lug Thickness	:	0.5 Inch
Bushing Thickness, t_B	:	0.09 Inch
Young's Modulus of Lug Material, E_L	:	3×10^4 Ksi
Young's Modulus of Bushing Material, E_B	:	3×10^4 Ksi
Poisson's Ratio of Lug Material, ν_L	:	0.3
Poisson's Ratio of Bushing Material, ν_B	:	0.3
Loading Pin Radius (= Lug Inner Radius–Bushing Thickness), r_i	:	0.75 Inch
t_B/r_i	:	0.12
E_B/E_L	:	1
Diametrical Interference, δ_D	:	0.008 Inch
σ_o	:	14 Ksi
R	:	0.1
Crack Type	:	Through-the-Thickness
c_o	:	0.025 Inch

Four sets of input data are presented for this problem. In the first data set, the residual stress and the normalized stress distribution across the net section are calculated from the already-available tables in the program by specifying 'METHOD' = -2 and 'IRSIG' = -1. In the second data set, the residual stress and the normalized stress distribution (obtained using the concentric cylinder equations and the finite element method) are input directly. In the third data set, the residual stress is calculated automatically ('IRSIG' = -1) and the normalized stress distribution is input directly. In the fourth data set, the residual stress is input directly and the normalized stress distribution is obtained from the

already-available tables ('METHOD' = -2). In the fourth data set, note that only t_B/r_i ('TBR') and E_B/E_L ('EBEL') are needed to interpolate the data from the tables. Values for parameters 'EL', 'DELD', 'POL' and 'POB' are not needed for such an interpolation, and will be ignored by the program if specified, without influencing the output results.

The above four input data sets show the flexibility with which the stress data can be input. All the four input data sets are equivalent and thus only one set of output data is included for this sample problem. The other three sets of output data would be the same, except for slight differences in the results due to computational round-offs.

The far-field loading is applied with a stress ratio of 0.1. However, the operating stress ratio across the net section of the lug will be different due to the presence of residual stress. In this case, the operating stress ratio ranges from 0.32 at the inner radius location to 0.64 at the outer radius location. Thus, for this problem, crack growth rate data corresponding to a stress ratio 0.5 are input, although the applied far-field stress ratio is 0.1.

A value of 2 has been input for parameter 'IGFTYP', selecting the original (unmodified) Green's function for the computation of stress intensity factors in this problem. The use of the original (unmodified) Green's function ('IGFTYP' = 2) is recommended for lugs with interference-fit bushings. The modified Green's function ('IGFTYP' = 1, the default value) should be used for lugs with no bushing, since the modification of Green's function accounts for the pin bearing pressure distribution variation with respect to crack length.

Comparison of experimental and analytical data of this sample problem is given in Figure 3-9.

```
 1:SVLR42 AND SVLR44
 2:     2      0      0      1
 3:    13      0
 4:         4.0     0.0537
 5:         5.0      0.106
 6:         7.0      0.247
 7:         9.0      0.482
 8:        11.0      0.833
 9:        13.0      1.310
10:        16.0      2.250
11:        20.0      3.930
12:        24.0      6.010
13:        28.0      8.350
14:        35.0     12.800
15:        50.0     29.000
16:        58.0     57.700
17:       250.5        0.5      -0.1
18:         0.0      250.5     179.7
19:    0      0
20:    1      1      1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:         1.0        1.0
23:        14.0        0.1     100.0
24:    0
25:    0      1
26:    1      1
27:    1     -2      0      2
28:  0.840000     3.375     0.5000
29:    0.0250   0.84750
30:   11     -1      0
31:    .12000    3.0E4       1.0     0.008      0.3      0.3
```

Line 16: METHOD = -2, IGFTYP = 2, use Green's function method calculating (cyclic) stress distribution using tables stored in the program. Also use unmodified Green's functions

Line 23: IRSIG = -1
Calculate residual stress using concentric cylinder equation

Line 24: TBR, EL, EBEL, DELD, POL, POB

```
 1:SVLR42 AND SVLR44
 2:      2     0     0     1
 3:     13     0
 4:          4.0     0.0537
 5:          5.0      0.106
 6:          7.0      0.247
 7:          9.0      0.482
 8:         11.0      0.833
 9:         13.0      1.310
10:         16.0      2.250
11:         20.0      3.930
12:         24.0      6.010
13:         28.0      8.350
14:         35.0     12.800
15:         50.0     29.000
16:         58.0     57.700
17:        250.5        0.5       -0.1
18:          0.0      250.5      179.7
19:     0     0
20:     1     1     1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:          1.0        1.0
23:         14.0        0.1      100.0
24:     0
25:     0     1
26:     1     1
27:     1     2     0     2  <----------  Line 16:  IGFTYP = 2, use unmodified
28:   0.840000      3.375     0.5000                 Green's function
29:     0.0250    0.84750
30:    11     1     0
31:         .000      3.418     22.525
32:         .050      3.100     20.833
33:         .151      2.517     18.091
34:         .252      2.041     15.985
35:         .353      1.752     14.332     Lines 23, 25*: Stress distribution
36:         .454      1.491     13.012                    (cyclic and residual
37:         .555      1.299     11.939                    stresses)
38:         .656      1.088     11.057
39:         .757      0.906     10.323
40:         .858      0.655      9.704
41:         .958      0.368      9.179
```

```
 1:SVLR42 AND SVLR44
 2:      2      0      0      1
 3:     13      0
 4:          4.0      0.0537
 5:          5.0       0.106
 6:          7.0       0.247
 7:          9.0       0.482
 8:         11.0       0.833
 9:         13.0       1.310
10:         16.0       2.250
11:         20.0       3.930
12:         24.0       6.010
13:         28.0       8.350
14:         35.0      12.800
15:         50.0      29.000
16:         58.0      57.700
17:        250.5         0.5        -0.1
18:          0.0       250.5       179.7
19:      0      0
20:      1      1      1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:          1.0         1.0
23:         14.0         0.1       100.0
24:      0
25:      0      1
26:      1      1
27:      1      2      0      2
28:   0.840000       3.375      0.5000
29:     0.0250     0.84750
30:     11     -1      0
31:     .12000      3.0E4         1.0       0.008       0.3       0.3
32:                 3.418
33:                 3.100
34:                 2.517
35:                 2.041
36:                 1.752
37:                 1.491
38:                 1.299
39:                 1.088
40:                 0.906
41:                 0.655
42:                 0.368
```

Line 16: IGFTYP = 2, use unmodified Green's function

Line 23: IRSIG = -1
Calculate residual stress using concentric cylinder equation

Line 25**: Cyclic stress distribution

```
 1:SVLR42 AND SVLR44
 2:     2     0     0     1
 3:    13     0
 4:         4.0    0.0537
 5:         5.0     0.106
 6:         7.0     0.247
 7:         9.0     0.482
 8:        11.0     0.833
 9:        13.0     1.310
10:        16.0     2.250
11:        20.0     3.930
12:        24.0     6.010
13:        28.0     8.350
14:        35.0    12.800
15:        50.0    29.000
16:        58.0    57.700
17:       250.5       0.5       -0.1
18:         0.0     250.5      179.7
19:     0     0
20:     1     1     1
21: CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
22:         1.0       1.0
23:        14.0       0.1      100.0
24:    0
25:    0     1
26:    1     1
27:    1    -2     0     2
28:  0.840000     3.375     0.5000
29:    0.0250   0.84750
30:   11     1     0
31:   .12000       0.0        1.0     0.000     0.0     0.0
32:                        22.525
33:                        20.833
34:                        18.091
35:                        15.985
36:                        14.332
37:                        13.012
38:                        11.939
39:                        11.057
40:                        10.323
41:                         9.704
42:                         9.179
```

Line 16: METHOD = -2, IGFTYP = 2, use Green's function method calculating (cyclic) stress distribution using tables stored in the program. Also use unmodified Green's functio

Line 24: Only TBR (= 0.12) a EBEL (= 1.0) a input.

Line 25***: Residual stress distribution

CONSTANT AMPLITUDE RATE OF GROWTH OF ONE END OF A CRACK

STRESS INTENSITY (^K) KSI X SQ. ROOT OF INCHES	CRACK GROWTH RATE (DA/DN) (MICROINCHES/CYCLE)	FORMAN'S CONSTANTS C	N
4.000	.054		
		.10028-06	3.01037
5.000	.106		
		.24149-06	2.46433
7.000	.247		
		.18823-06	2.59236
9.000	.482		
		.16959-06	2.63983
11.000	.833		
		.18459-06	2.60448
13.000	1.310		
		.25760-06	2.47455
16.000	2.250		
		.38229-06	2.33217
20.000	3.930		
		.72756-06	2.11736
24.000	6.010		
		.15881-05	1.87173
28.000	8.350		
		.42035-05	1.57962
35.000	12.800		
		.20371-05	1.78337
50.000	29.000		
		.56288-09	3.87793
58.000	57.700		

KC VALUE USED IN FORMAN EQUATION IS 250.500 KSI*SQRT(IN.)
CONSTANT AMPLITUDE RATE IS .5000
MINIMUM ALLOWABLE STRESS RATIO IS -.1000

* MISSION NO. 1 STRESS SPECTRUM FOR CONSTANT AMPLITUDE WITH SIGMA(MAX)= 14 KSI AND R=0.1
ONE FLIGHT OF THIS MISSION IS EQUIVALENT TO 1.00 HOURS

LAYER NO.	SMAX (KSI)	SMIN (KSI)	R (SMIN/SMAX)	^S (SMAX-SMIN)	CYCLE/PASS
1	14.000	1.400	.100	12.600	100.0

SVLR42 AND SVLR44

FORMAN'S EQUATION IS USED IN ANALYSIS

* THRU CRACK EMANATING FROM A LUG HOLE *

RADIUS OF THE HOLE IS .8400 IN.
WIDTH OF THE LUG IS 3.3750 IN.
THICKNESS OF THE LUG IS .5000 IN.
RATIO OF W/D IS 2.0089

INITIAL CRACK LENGTH IS .0250 IN.
THE TENSILE YIELD STRENGTH IS 179.70 KSI
THRESHOLD ^K IS INPUT AS .000 KSI*SQRT(IN)
FRACTURE TOUGHNESS KC IS INPUT AS 250.500 KSI*SQRT(IN)

THE FOLLOWING TABLE IS CALCULATED FROM ALREADY AVAILABLE TABULAR STRESS CONCENTRATION FACTOR VALUES (FOR RO/RI= 2.0089,AND RI= .8400)

INTERFERENCE STRESSES IN THE FOLLOWING TABLE ARE CALCULATED USING THE FOLLOWING VALUES

BUSHING THICKNESS/PIN RADIUS	=	.1200
YOUNG'S MODULUS OF LUG	=	.3000+05KSI
(BUSHING/LUG) MODULUS RATIO	=	1.0000
DIAMETRAL INTERFERENCE	=	.8000-02INCH
POISSON'S RATIO OF LUG	=	.3000
POISSON'S RATIO OF BUSHING	=	.3000

A FAR FIELD STRESS OF 1 KSI AND A STRESS RATIO OF 0.1 IS ASSUMED IN THE CALCULATION OF FOLLOWING TABLE

EFFECTIVE UNFLAWED STRESSES ARE AS FOLLOWS :

(Y-RI)/RI	RESIDUAL STRESS	STRESS/UNIT LOAD	EFFECTIVE MAX. & MIN. STRESSES	
.000	22.525	3.418	25.943	22.867
.050	20.833	3.100	23.933	21.143
.151	18.091	2.517	20.608	18.343
.252	15.985	2.041	18.026	16.189
.353	14.332	1.752	16.084	14.508
.454	13.012	1.491	14.503	13.161
.555	11.939	1.299	13.238	12.069
.656	11.057	1.088	12.145	11.166
.757	10.323	.906	11.229	10.413
.858	9.704	.655	10.359	9.770
.958	9.179	.368	9.547	9.216

COMPUTED S.I.F. USING GAUSSIAN INTEGRATION
OF ORIGINAL GREEN'S FUNCTIONS

C	C/RI	K(MAX)	K(MIN)	^K	R	BETA(MAX)
.0042	.0050	3.3025	2.9113	.3912	.8815	28.6229
.0085	.0101	4.6622	4.1104	.5518	.8816	29.5723
.0169	.0202	6.1828	5.4525	.7303	.8819	26.7932
.0424	.0504	7.8826	6.9574	.9252	.8826	21.6042
.0678	.0807	9.5531	8.4406	1.1125	.8835	20.6993
.0847	.1009	10.3841	9.1819	1.2023	.8842	20.1245
.1271	.1513	12.4398	11.0221	1.4177	.8860	19.6844
.1695	.2018	14.0996	12.5195	1.5801	.8879	19.3218

.2119	.2522	15.8794	14.1307	1.7487	.8899	19.4634
.2542	.3027	17.5472	15.6422	1.9051	.8914	19.6338
.2966	.3531	19.1366	17.0832	2.0534	.8927	19.8237
.3390	.4036	20.6582	18.4677	2.1906	.8940	20.0179
.3814	.4540	22.2893	19.9528	2.3365	.8952	20.3632
.4237	.5045	23.8996	21.4225	2.4772	.8964	20.7139
.5085	.6054	27.3126	24.5366	2.7760	.8984	21.6094
.5932	.7062	31.0948	28.0046	3.0903	.9006	22.7769
.6780	.8071	36.5308	32.9971	3.5337	.9033	25.0305
.7204	.8576	42.1928	38.2034	3.9894	.9054	28.0468
.7627	.9080	49.8114	45.2430	4.5684	.9083	32.1783
.8051	.9585	59.3986	54.1500	5.2487	.9116	37.3482

PREDICTED CRACK GROWTH HISTORY (UNIFORM THRU-CRACK REGION)

CRACK LENGTH (INCHES)	TIME (PASSES)	GROWTH RATE (DA/DF) (INCHES/PASS)	ALPHA-A (INCHES**.5)	K(MAX) KSI*SQRT(IN.)	TIME (HOURS)
.0250	.000	.000000	6.7210	18.1615	.00
.0300	91.067	.000076	7.0552	19.0494	91.07
.0350	152.528	.000087	7.3895	19.9373	152.53
.0400	206.662	.000098	7.7238	20.8252	206.66
.0450	254.812	.000110	8.0551	21.6987	254.81
.0500	298.322	.000120	8.3836	22.5592	298.32
.0600	373.630	.000145	9.0406	24.2803	373.63
.0700	436.554	.000173	9.6610	25.8989	436.55
.0800	491.142	.000194	10.1512	27.1539	491.14
.0900	540.003	.000216	10.6388	28.3903	540.00
.1000	584.136	.000238	11.1239	29.6097	584.14
.1200	660.105	.000289	12.0942	32.0485	660.10
.1400	724.240	.000335	12.9441	34.1345	724.24
.1600	780.371	.000378	13.7275	36.0252	780.37
.1800	830.236	.000424	14.5406	37.9676	830.24
.2000	874.744	.000474	15.3806	39.9568	874.74
.2500	967.942	.000599	17.3800	44.6710	967.94
.3000	1043.811	.000719	19.2578	49.0752	1043.81
.3500	1108.207	.000833	21.0816	53.2701	1108.21
.4000	1163.895	.000962	22.9971	57.6393	1163.89
.4500	1212.159	.001110	24.9567	62.0748	1212.16
.5000	1253.895	.001286	26.9703	66.6346	1253.89
.6000	1320.151	.001732	31.5278	76.6753	1320.15
.7000	1361.775	.003073	39.4703	93.9303	1361.77
.8000	1373.336	.014226	58.2391	132.8651	1373.34

FAILURE DUE TO NET SECTION YIELD (STRESS = 497.38 KSI)

NOTE : ONE PASS IS EQUIVALENT TO 100.0000 CYCLES
ONE PASS IS EQUIVALENT TO 1.0000 FLIGHT HOURS

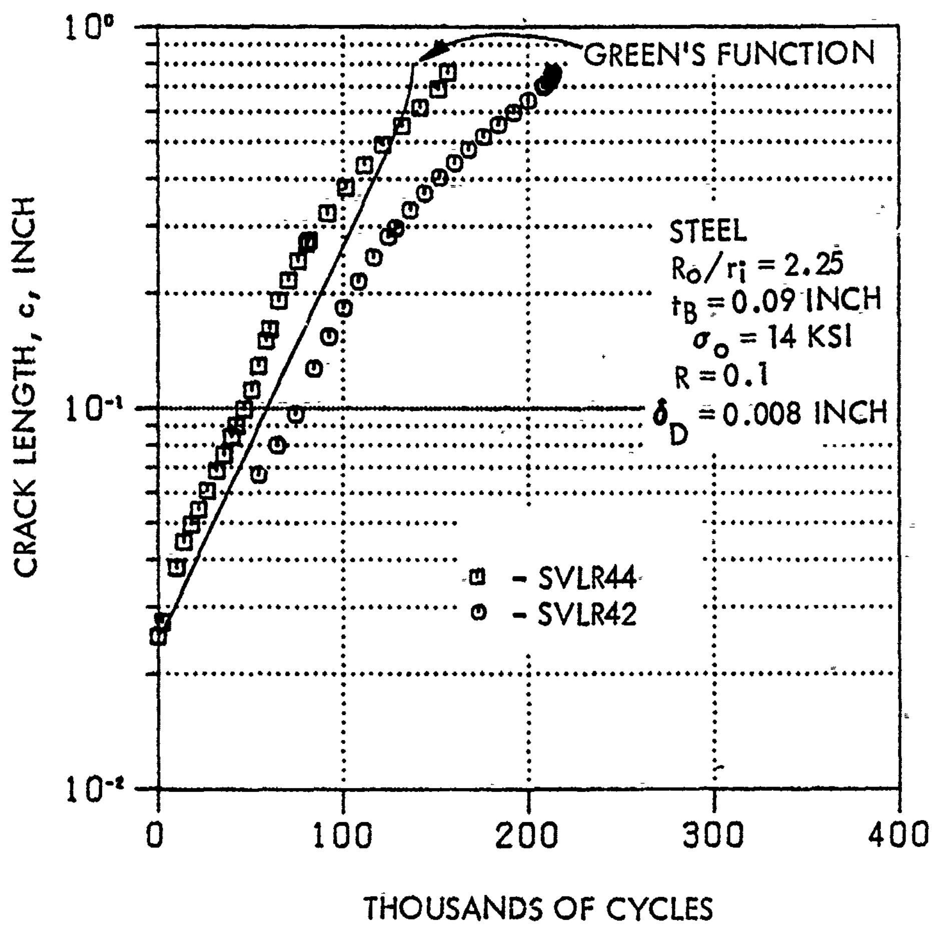

Figure 3-9. Through-the-Thickness Crack Growth Data and Prediction, Steel Lug with Steel Bushing, R_o/r_i=2.25, t_B=0.09 Inch, σ_o=14 KSI, R=0.1, δ_D=.008 Inch

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